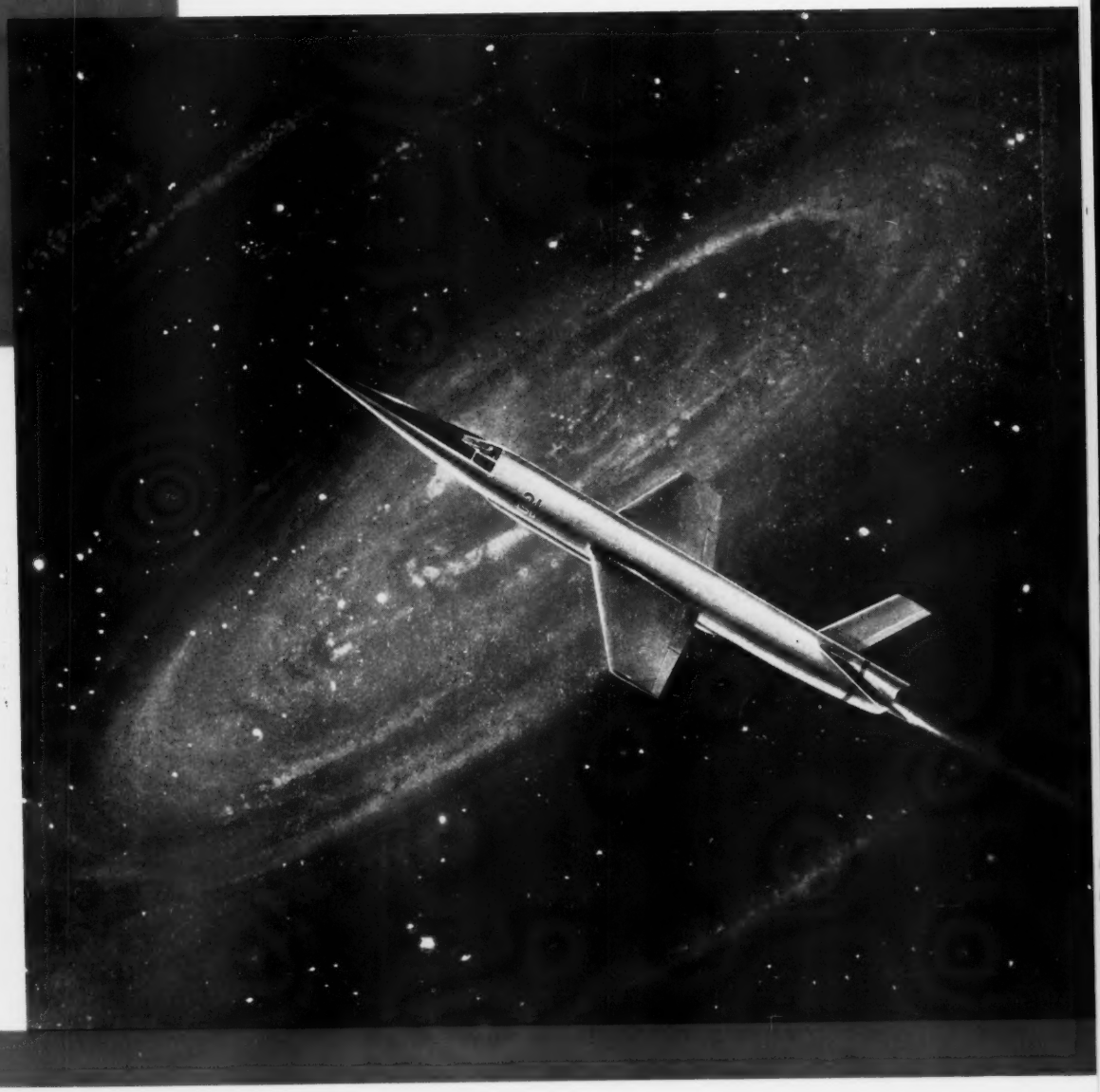
Aeronautical Engineering REVIEW



ELECTRONICS IN AVIATION — **May, 1955**

New Holley turboprop power control installed in Lockheed R7V-2

One hundred and six passengers or 36,000 pounds of cargo cruise at speeds up to 440-miles-per-hour in the Navy's new Lockheed R7V-2 turboprop Super Constellation. Four Pratt & Whitney Aircraft axial flow T-34 propeller turbine engines develop a total of 22,000 horsepower for take-off. Each of the four is automatically controlled by a new Holley gas turbine power control.

High performance turboprop engines like the T-34 demand extreme accuracy in fuel metering to maintain their high performance ratings and at the same time control operation within satisfactory limits. Through a system of accurately measuring four separate senses, the Holley control automatically meters corrected fuel flows to the engine in accordance with the engine operating requirements.

The Holley gas turbine control is the result of intensive research and development to provide a light weight, compact means of accurately metering fuel consistent with engine requirements.

This and other Holley developed fuel metering devices have played an important role in our country's undisputed leadership in the design, development and manufacture of superior aircraft.

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Leader In The Design, Development, and Manufacture of Aviation Fuel Metering Devices.

Aeronautical Engineering REVIEW

Vol. 14—No. 5 May, 1955

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Cover—Electronics will play an important role in future ventures into space, as depicted by artist R. W. Bradford for the Department of Aeronautical Engineering, Institute of Aerophysics, University of Toronto.

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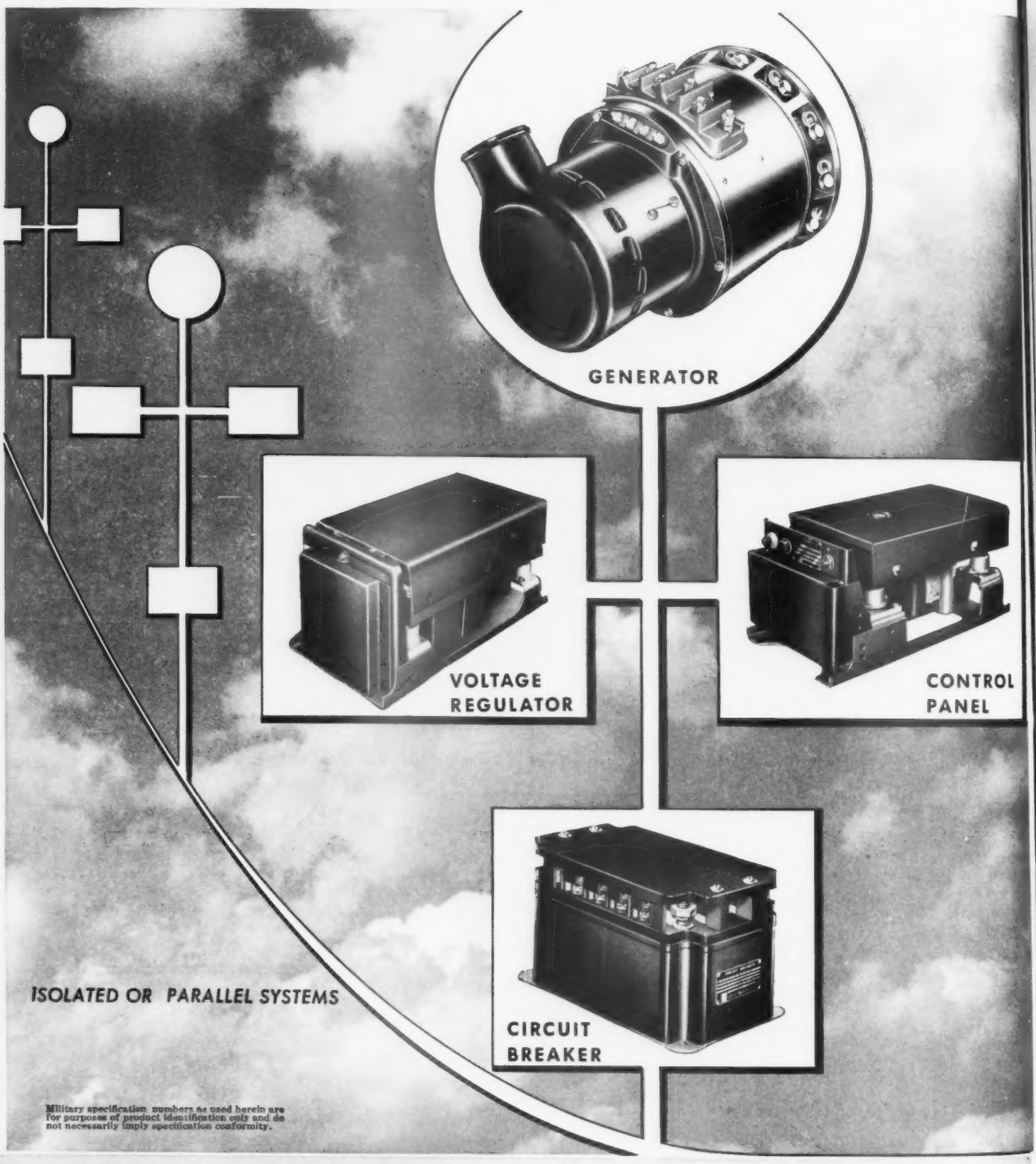
A-C SYSTEMS FOR AIRCRAFT



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JACK & HEINTZ *Rotomotive*

I.A.S. News Notes

May 1955

INTERNATIONAL CONFERENCE OPENS JUNE 20

The Fifth International Aeronautical Conference, a joint meeting of the RAeS and IAS, will open Monday morning, June 20, at 9:45, with registration starting at 9:00 a.m. in the IAS Building, 7660 Beverly Blvd., Los Angeles.

* * * * * *

TWO FELLOWSHIPS AWARDED AT PRINCETON

The IAS has awarded Fellowships in Flight Test Engineering, contributed by an anonymous donor, to William B. Browne, a senior at North Carolina State College, and Warren J. North, an aeronautical research scientist and pilot at Lewis Flight Propulsion Laboratory, NACA. The Fellowships permit two years of graduate study at Princeton University.

* * * * * *

IAS WESTERN STUDENT CONFERENCE

The Fifth Annual Western Regional Student Conference, sponsored by the IAS, will be held in Los Angeles May 11-13. Students from U.C.L.A., Cal Tech, University of Southern California, Northrop Aeronautical Institute, University of Washington, Stanford, the Naval Post Graduate School, and Oregon State will present technical papers, and awards will be given at a banquet in the IAS building Friday evening, May 13.

* * * * * *

NATIONAL MEETINGS CALENDAR

May 9-11 National Conference on Aeronautical Electronics, Hotel Biltmore, Dayton, Ohio.
May 18-20 National Telemetering Conference, Hotel Morrison, Chicago.
June 20-23 Fifth International Aeronautical Conference, IAS Building, 7660 Beverly Blvd., Los Angeles, California.
June 23-25 Heat Transfer and Fluid Mechanics Institute, UCLA, Los Angeles.
Aug. 8-10 Turbine-Powered Air Transportation Meeting, Seattle, Wash.

CALENDAR OF SECTION MEETINGS

May 4 - Philadelphia Section: Skyview Dining Room, Philadelphia International Airport. Social Period, 6:30 p.m.; Dinner, 7:00 p.m.; Meeting, 8:00 p.m. "Operations Research in Military Aviation" by Leroy A. Brothers, Head, Operations Analysis Div., Hdqs., USAF.

May 5 - St. Louis Section: Gatesworth Hotel. Dinner Meeting with SAE, 8:00 p.m. Mayor Raymond R. Tucker will speak.

I.A.S. News Notes (con't.)

CALENDAR OF SECTION MEETINGS (CON'T.)

May 5- San Diego Section: IAS Building. Meeting, 8:00 p.m. "Powered Flight Controls" by Mr. Chapman, Convair-San Diego.

May 10- Los Angeles Section: IAS Building. Specialist Meeting, 8:00 p.m. "Analytical Prediction of Missile Guidance Accuracy" by Warren E. Mathews, Senior Staff Physicist, Hughes Aircraft Company.

May 11- Niagara Frontier Section: Airways Hotel, Buffalo Airport. Dinner, 7:45 p.m. "Island-Hopping in the Antilles" by Robert M. Stanley.

May 11- Washington Section: International Room, Occidental Restaurant. Social Hour, 6:00 p.m.; Dinner, 6:45 p.m.; Meeting, 8:00 p.m. "Private Aviation" by J. B. Hartranft; "Business Aviation" by J.H. DuBuque; "Agricultural Aviation" by J. R. Allgyer.

May 14- San Diego Section: IAS Building. Annual Spring Dance, 9:00 p.m.

May 17- Seattle Section: Benjamin Franklin Hotel. Dinner Meeting, 6:00 p.m. "Operational Factors of Jet Transports" by R. D. Kelly, Superintendent of Technical Development, United Air Lines.

May 19- Los Angeles Section: IAS Building. Social Hour, 6:00 p.m.; Dinner, 7:00 p.m.; Meeting, 8:15 p.m. "The Problem of Weightlessness" by Heinz Haber, Associate Physicist, Dept. of Engineering, UCLA.

May 19- Twin Cities Section: Worwa's Cafe. Social Hour, 6:00 p.m.; Dinner, 6:45 p.m.; Meeting, 8:00 p.m. Talk by H. Guyford Stever, Chief Scientist, USAF.

May 24- Indianapolis Section: Athenaeum Turners Club. Social Hour, 6:30 p.m.; Dinner Meeting, 7:00 p.m. "A for Atom" by T. N. Darley, General Electric Company.

May 24- Los Angeles Section: IAS Building. Specialist Meeting, 8:00 p.m. "Predicting Transition in Incompressible Flow" by A. M. O. Smith, Supervisor, Aerodynamic Research, Douglas Aircraft-El Segundo.

May 26- Dayton Section: Cordell's Supper Club, Fairborn. Dinner, 6:30 p.m.; Technical Discussion, 7:30 p.m. "Pilot vs Computer" by Capt. Neil R. Burch, USAF, Aero Medical Laboratory, WADC.

May 26- St. Louis Section: Engineers Club. Meeting, 8:00 p.m. Panel discussion on new air frame construction methods and techniques.

May 26- San Francisco Section: Ramor Oaks, Atherton. Meeting, 7:00 p.m. Subject, the Convair VTO airplane.

May 28- Hampton Roads Section: Newport News Shipyard. Tour of the USS Forrestal with other engineering groups, 10:00-12:00 a.m. In the evening, Dinner Dance at Williamsburg Lodge, 6:30 p.m.

June 4- Los Angeles Section: Confidential Field Trip to Jet Propulsion Laboratory, Pasadena, 10:30 a.m.

June 4- New York Section: Port Washington, L. I. Tour of U. S. Navy's Special Devices Center, Sands Point, 12:00 noon. Picnic lunch.

June 14- Los Angeles Section: IAS Building. Specialist Meeting, 8:00 p.m. "Boost Period Launching Error" by William M. Bleakney, Senior Staff Physicist, Hughes Aircraft Company.

* * * * * * * *

IAS News

A Record of People and Events of Interest to Institute Members

Fifth RAeS-IAS Conference

Technical Sessions on June 20–22. Bane and Chanute Awards Presented June 23.

THE FIFTH INTERNATIONAL AERONAUTICAL CONFERENCE, a joint meeting of the Royal Aeronautical Society and the Institute of the Aeronautical Sciences, will open on June 20, 1955, at the IAS building, 7660 Beverly Blvd., Los Angeles. Welcoming addresses will be delivered at this time by RAeS President Norbert Edward Rowe, FIAS, Technical Director, Blackburn & General Aircraft, Ltd., England, and by IAS President Robert E. Gross, AMIAS, President and Chairman of the Board, Lockheed Aircraft Corporation.

Eight technical sessions have been planned for this RAeS-IAS conference—two on the twentieth, three on the twenty-first, and three more on the twenty-second. At press time, a total of 18 papers had been scheduled for presentation at the sessions. Nine of these papers will be given by the British delegates, one by a Canadian, and the remaining eight by American delegates.

The nine British papers and their authors are:

N. E. Rowe
RAeS President

"Operation of Turbo-Prop Aircraft" by P. G. Masefield, Chief Executive, British European Airways; "Power Plants for Supersonic Flight" by E. S. Moult, Chief Engineer, The de Havilland Engine Company, Ltd.; "Low Consumption Jet Engines" by A. A. Lombard, Chief Projects, Rolls-Royce Limited; "Interaction Between Shock Waves and Boundary Layers and Its Effects in High-Speed Flight" by D. W. Holder, Wind Tunnels, National Physical Laboratory; "Boundary Layer Effects in Supersonic Flow" by R. J. Monaghan, Royal Aircraft Establishment; "Some Influences of Equipment Installations and Systems on Aircraft Design" by C. F. Joy, Chief Designer, Handley Page, Limited; "Impact of Fatigue on Civil Aviation" by P. B. Walker, Head of Structures, RAE; "Jet Noise" by F. B. Greatrex, Chief Development Engineer, Installation Division, Rolls-Royce; and "Some Modern Structural Problems" by W. S. Hemp, Head, Department of Aircraft Design, and Professor, Aircraft Structures and Aero-Elasticity, College of Aeronautics, Cranfield.

The single Canadian paper, which will be on "Shock Tubes," will be delivered by G. N. Patterson, Director, Institute of Aerophysics, and Head, Department of Aeronautical Engineering, University of Toronto.

The eight American papers and their authors are:

"Combustion for Aircraft Engines" by W. T. Olson, Lewis Flight Propulsion Laboratory, NACA; "The Variable Stator Engine" by C. J. Walker, Manager, Preliminary Design, and Gerhard Neumann, Manager, Development Engineering, Aircraft Gas Turbine Division, General Electric Company; "Design of High-Speed Aircraft" by E. H. Heinemann, Chief Engineer, El Segundo Division, Douglas Aircraft Company, Inc.; "Power Control Systems for Aircraft" by John L. Ludwig, Staff Engineer, Controls and Hydraulics, Chance Vought Aircraft, Incorporated; "Hypersonic Flow" by Lester Lees, Associate Professor, Aeronautics and Applied Mechanics, California Institute of Technology; "Design of Large Helicopters" by Bartram Kelley, Chief Engineer, Helicopter Division, Bell Aircraft Corporation; "Airline Use of Elementary Statistical Methods in Aircraft Performance Measurement" by W. C. Mentzer, General Manager—Engineering, United Air Lines, Inc.; and "Some Results from the Princeton University Smoke Tunnels" by David C. Hazen, Assistant Professor, Department of Aeronautical Engineering, Princeton University.

The Thurman H. Bane and The Octave Chanute awards for 1954 will be presented to the respective recipients at the dinner-dance to be held on June 23 at the Palladium in Los Angeles. There will be no speaker on this occasion, only short talks by the RAeS-IAS presidents.

R. E. Gross
IAS President

Brooklyn Poly Welcomes Students at Northeastern Regional Student Conference

The Polytechnic Institute of Brooklyn entertained students from colleges all over the east coast who were attending the IAS Third Northeastern Regional Student Conference on February 25 and 26.

The colleges represented at the conference were the University of Maryland, Princeton University, Massachusetts Institute of Technology, U.S. Naval Academy, Rensselaer Institute of Technology, and Polytechnic Institute of Brooklyn. The faculty advisers of the Student Branches, Prof. Lawrence A. Guess of the University of Maryland and Prof. Joseph Kempner of the Polytechnic Institute of Brooklyn, also attended the conference. The staff of the Institute of the Aeronautical Sciences was represented at the gathering by Miriam E. Hauser.

The purpose of the student conference is to give graduate and undergraduate students the opportunity to compete for awards and recognition for original papers. This conference is held annually in different schools. This year, Brooklyn Poly was chosen to be the host since the college is celebrating its Centennial.

Registration for the conference began at 9:30 a.m. on Friday, the twenty-fifth. The visiting students were welcomed by the officers of the Brooklyn Poly Student Branch and introduced to the other students and instructors who were present.

Later in the morning, the group assembled in the student lounge, and the conference formally began. Louis Divone, the Chairman of Poly's IAS Branch, made a short welcoming speech and then introduced the first speaker, the President of Brooklyn Poly, Harry S. Rogers.

President Rogers spoke to the group about the engineer's part in our civilization and the goals for which an engineer should strive. He said that, as a young engineer, he had believed that the nature of our civilization was based on technological advances; as he became more experienced, he found out "the great problems of the world are not solved on a slide rule." He then said that the technical areas have supplied the means for human ends, and as an example, he stated that the great freedoms of the world are now protected by the slide rule. In summary, President Rogers said that the engineer must have an understanding of the human aspects of life as well as the goals of his work.

The next speaker was Nicholas J. Hoff, Chairman of the Department of Aeronautical Engineering and Applied Mechanics, Polytechnic Institute of Brooklyn, who spoke about some of the research work being done in the school. Hoff opened his talk by giving a tribute to the IAS; he said, "The Institute of Aeronautical Sciences is one of the best established and best endowed engineering organizations in this country, even though it is one of the youngest." In his subsequent discussion of research at Brooklyn Polytech, he mentioned studies in high-temperature creep being carried on in a small laboratory in school and probings into the field of supersonic aerodynamics at the laboratory in Freeport, L.I.

At the conclusion of the speeches, Chairman Louis Divone supervised the selection of a board of judges from among the students to vote on the excellence of the students' papers.

The first undergraduate paper was presented by Forman Williams of Princeton University. His talk was about the calibration of a recently built wind tunnel at Princeton. The tunnel he described is a dual-purpose setup in which the same power supply and fan is used to operate both a two-dimensional and a three-dimensional test section. He showed slides of the tunnel and explained how the duality was accomplished. There are three legs to the tunnel: the center houses the fan, one side is a two-dimensional test section, and the other a three-dimensional section. The flow is diverted into either one or the other test leg by an adjustable turning vane section. In his discussion of the calibration, he explained the use of an ordinary doctor's stethoscope for qualitatively determining turbulent portions of the flow in the tunnel.

The next paper was presented by Frank Schlee of the Polytechnic Institute of Brooklyn. He spoke on the problems in the use of strain gages at rapidly changing high temperatures. Schlee said that aerodynamic heating at high speed induces thermal shock stress in aircraft structures and that measuring these stresses is a goal engineers are striving for now. At present the problem seems unsurmountable because no means are available which can interpret the rapid changes in stress and temperature, both of which affect the resistance of the strain-gage wire.

The third paper was presented jointly by Roger Barron and Huston Landis of Princeton University. They contended that it is possible to solve the problems connected with the canard airplane and make this aircraft completely practical. They said that the main difficulty with this design, in which the tail is forward of the wing, is that if the tail stalls out, the plane becomes completely uncontrollable. Their solution to this problem is to use a stabilizer having a very large lift coefficient. To achieve this, they designed a delta plan-form wing incorporating two boundary-layer control devices and tested it in a smoke tunnel. The results of their tests indicated that there is considerable increase in lift when using boundary-layer control.

In the afternoon, graduate papers were presented. The first paper was given by Earl W. Erickson of M.I.T., and was entitled "Study of Invariant Parameters for Cruise Control Techniques to Obtain Maximum Range for Turbojet Aircraft." Erickson pro-

(*Continued on page 125*)

Shown at the Awards Banquet during the Third Northeastern Regional Student Conference is a part of the speakers table. From *left to right* are: Martin Bloom, Paul A. Libby, Thomas J. Meskel, Nicholas J. Hoff, Richard W. Porter, Louis Divone, and Joseph Kempner. This conference was hosted by the Polytechnic Institute of Brooklyn on February 25–26, 1955.

Aerophysics Development Corporation Joins IAS

Aerophysics Development Corporation, of Pacific Palisades, Calif., has joined the IAS as a Corporate Member.

Recently acquired by Studebaker-Packard Corporation as a wholly-owned subsidiary, the firm has specialized in development work on guided missiles. It also is equipped to handle broad development work in the whole area of aerophysics, according to company officials.

The acquisition represents a major step by Studebaker-Packard into the field of scientific research and development, giving the parent corporation an organization of engineers and scientists working on the basic development of key defense items. The subsidiary has a staff of about 200. It holds possibilities for future work of pioneering importance in commercial fields as well as in defense, officials said, but the immediate emphasis will be placed on defense work.

William Bollay, FIAS, who founded Aerophysics Development Corporation in 1951, continues as President. He is a member of the Air Force Scientific Advisory Board.

Before starting his own company, Bollay headed the Aerophysics Laboratory of North American Aviation, Inc. He delivered the Wright Brothers Lecture in 1950, speaking on "Aerodynamic Stability and Automatic Control."

Wichita Univ. Presents Boundary Layer Control Course

An intensive and classified course on boundary-layer control will be offered on June 13–24 at the University of Wichita. This is believed to be the first formal course on this subject to be given at any university.

The primary purpose of this course is to review the boundary-layer theories and to present the design procedures for the application of boundary-layer control which are now available. The "case" method will be used with particular applications being outlined, specific results identified, and general conclusions reached for similar cases.

Each person taking this course—only 30 will be permitted to enroll—must be competent in aerodynamics and fluid mechanics. He is expected either to hold a degree in aeronautical or mechanical engineering or to present records that indicate a satisfactory background both as to experience and education.

Harold R. Larsen, MIAS, Vice-President of Servomechanisms, Inc., has been given added responsibilities as General Manager of the company's Eastern and Western Divisions. A 1938 graduate of the University of Minnesota, he is in charge of sales, engineering, and production.

News of Members

▸ **H. Norman Abramson** (M), Associate Professor of Aeronautical Engineering, The Agricultural and Mechanical College of Texas, has been appointed an Associate Editor of *Applied Mechanics Reviews*.

▸ **Louis G. Dunn** (F), Associate Director, Guided Missile Division, The Ramo-Wooldridge Corporation, was awarded a Certificate of Appreciation by the Department of the Army for his work in missile ordnance, including development and completion of the Army's surface-to-surface guided missile, the Corporal. The citation, signed by Secretary of the Army Robert T. Stevens, honored Dunn for his work from 1947 to 1954 as Director of the Jet Propulsion Laboratory, operated for the Army by California Institute of Technology.

▸ **Major Lester D. Gardner,** IAS Founder, Honorary Fellow, and Benefactor, has been associated with Flight Safety Foundation, Inc., and during the absence of its President, Adm. John H. Towers, USN (Ret.), Major Gardner has assumed some of the President's functions.

▸ **John J. Green** (F), Chief, Division "B" (armaments and aeronautics), Defence Research Board, Canada, and first President, Canadian Aeronautical Institute, takes over the post of Defence Research Member, Canadian Joint Staff, Washington, D.C., this summer. Among his chief duties will be the promotion and maintenance of an increasing flow of scientific information about defense projects between Canada and the United States, particularly in the fields of aircraft and guided weapons.

▸ **R. R. Higginbotham** (AF), Chief Power Plant Engineer, Republic Aviation Corporation, has been placed in charge of power plant design on all projects. This change is part of a move at Republic to facilitate the engineering of aircraft subsystems.

▸ **Dr. Barry G. King** (M), Research Executive, Medical Division, Office of Aviation Safety, CAA, was the recipient of the Exceptional Service Award. This gold medal was given "for exceptional and extremely valuable accomplishments in the field of aviation safety through medical research, through designs of safety devices for exit and escape from ditched aircraft, and through noteworthy contributions to aviation medical literature and medical training programs."

▸ **James S. McDonnell** (F), President, McDonnell Aircraft Corporation, was recently named the 1955 Chairman of the United States Committee for the United Nations by Secretary of State John Foster Dulles. One purpose of this committee is to promote October 24 as United Nations' Day.

▸ **Mundy I. Peale** (AM), President, Republic Aviation Corporation, was presented with Italy's highest civilian award of merit, the Order of Merit of the Italian Republic. Mr. Peale was commended for the work of his company in establishing a cooperative manufacturing program between Republic and the Finmeccanica Company of Naples to produce spare parts for the F-84 Thunderjet supplied to Italy under North Atlantic Treaty and mutual assistance pacts.

▸ **Charles R. Reid** (TM), Vice-President, The Vitroseal Corporation, has returned from a tour of duty with the Navy. While stationed in Norfolk, Va., he was Maintenance Officer of Air Anti-Submarine Squadron Thirty (VS-30) at the Naval Air Station.

▸ **Igor I. Sikorsky** (HF), Engineering Manager, Sikorsky Aircraft Division, United Aircraft Corporation, was awarded the James Watt International Medal for 1955 by Great Britain's Institution of Mechanical Engineers. This medal, given every 2 years, was presented to Mr. Sikorsky in recognition of his life's work in applying science to the progress of mechanical engineering through pioneering development of aircraft of various types, particularly helicopters.

▸ **Ray P. Whitman** (AF), First Vice-President, Bell Aircraft Corporation, has been elected a Director of

(*Continued on page 125*)

By

Rear Adm. Selden B. Spangler, USN

Commander

U.S. Naval Air Development & Material Center

Luncheon address presented at the Twenty Third Annual Meeting, IAS, New York, January 24–27.

Guest Editorial

Electronics in Aviation

As a matter of semantics, I am herein defining electronics as not including those things that in pre-black-box days we used to call the electrical system of the airplane. Just as the term *scientist* is now used to describe all the personnel in a laboratory short of the boy who empties the waste baskets, the term *electronics* has been expanded to include the motor that operates the cowl flaps. I shall try to avoid that use of the term since I feel the profession of electrical engineer is an honorable and important one in itself. However, the term electronics will be used to include not only the black boxes but also the vital areas of radiation and propagation. Not the least of the advances made in the application of electronics to aircraft has been the development of modern antennas and the adaption of the aircraft to them. Radar in modern high-speed aircraft would have been wholly impractical with the old hedgehog antenna. Because the electronic information circuit, with the operator, is a closed loop, the successful operation of the airplane is vitally affected by the propagation characteristics of the system. Since these characteristics are dependent in part on—for example, the radiation frequency—the mission of the airplane, the number of crew available, and the size and general configuration of the air frame must all be considered when matching the electronics to the aeronautics to form the complete operating team.

The concept of electronics *and* aviation naturally arises from the great increase in airplane performance with no corresponding increase in man's time constants. It is not only impossible to carry on modern aerial combat with man's vision restricted to something like 10 to 15 sec. in terms of distance at the speeds we now know are entirely practicable, but man's reaction time is such as to render him almost helpless in maintaining the airplane even in straight and level flight without electronic help. It is only by the use of such devices as—for example, the yaw dampener, whose reaction time is on the order of 20,000 times as fast as man's—that we can properly control the airplane. It has become obvious that, in many phases of military aviation, progress will be unproductive unless matched by similar or even greater progress in the practical application of electronics. This is not to say that the age of push-button warfare is here if by push-button warfare is meant the abolition of manned aircraft. Science has yet to develop, even in concept, a complete substitute for the human brain. As one facet of the problem, the Navy long ago learned that, if it is desired to hit a specific target, the bomb must be carried close enough to that target before it is released to assure a hit, and therefore the dive bomber was developed. Electronics can and does extend the range at which the bomb may be dropped and still assure a hit, but it has not developed a substitute for the pilots' command decision to drop that bomb on that target.

At the Naval Air Development Center, one of the units of my command, we have the Typhoon computer, one of the largest and most accurate of the analog super slide rules. It can take almost any chunk of data and

wring the last drop of mathematical meaning out of it rapidly and accurately. This device presents some of both the faults and virtues of electronic equipment. It is large and heavy, contains a multitude of delicate tubes and other circuitry devices, and, on occasion, gives every symptom of developing mental aberrations. It can, however, accomplish the solution in real time of any six linear or nonlinear simultaneous differential equations you care to feed it. It is an extraordinarily useful tool, and that is the catch, of course. It is only a tool, and, as a tool, is no better than the intelligence of the man who feeds it the right data in the right form and directs its efforts.

Over the last 20 years, the progress of aviation has put an emphasis on the science of electronics it could probably have achieved in no other way. Military aviation has been a real challenge to electronics. Has electronics met that challenge? The answer cannot be either an unqualified "yes" or "no." As a science it is still in its teens and on occasion reminds you forcibly of a 17-year-old boy. In those things in which he has a real interest—making model airplanes, say—he does an outstanding, imaginative job; but he will not cut the grass without the threat of loss of his allowance. The causes of this failure to meet completely the needs of aviation are many and varied, ranging all the way from misunderstanding and vacillation on the part of the user to lack of understanding of the problem on the part of the developer. Whatever the cause, however, it appears to be reasonably evident that the demands on electronics are beyond what the current capabilities of the industry can meet on a presently envisaged military time scale.

While not proposing to treat these causes in detail, I shall mention several that might merit some discussion. Being a relatively young science, electronics has not yet moved far enough from the scientist to achieve in all cases practical, useful pieces of equipment. Perhaps this has important desirable features in a field such as that of electronics which has not nearly reached the median point in its curve of development. It is most certainly true that it is only through the devoted and inspired work of the research scientist and the development engineer that future progress can be assured. On the other hand, the participation of the research man in development and of the development man in production frequently produces a wholly impractical piece of equipment. Such an equipment may require a Ph.D. to operate it and an M.S. to maintain and service it, neither of whom is likely to be obtainable in the right place at the right time and at the salaries payable to enlisted men or officers. It is absolutely essential that we hold back production of our new developments until we can assure ourselves that adequate thought has been put on the simplification of the operation and maintenance feature of the equipment. It must not be forgotten that a combat mission is normally based not on the *possibilities* of the airplanes and their equipment but on the *probabilities* that they can successfully carry out their missions. Known deficiencies in performance can be accounted for in the setting up of the mission, unknown deficiencies in operability or reliability can only result in aborted missions. Only a military commander of what I call the "throw it over anyway, it might do some good" school of thought would take a chance with equipment of unknown and suspect quality. This description stems from a story of my Naval Academy days. For training in the art of handling ships we had a group of World War I subchasers that were gotten under way and brought back alongside the piers to demonstrate proper methods of docking and undocking. These ships had rather cranky gasoline engines that always stopped at crucial moments. On one such occasion, our Skipper, an old ex-Boatswain, in trying to come alongside, found himself with considerable way on the ship and headed straight toward the pier with no engines. He shouted up to the midshipman on the forecastle, "Let go the port anchor." On receiving the reply, "But there's no line tied to it," he responded, "Well, throw it over anyway, it might do some good."

The inevitable result of sending breadboard models to sea as production equipments is that the operating forces rapidly lose faith in the equipment and in the designer, which means lost time for both which can never be regained.

It is a well-known fact that there is a substantial shortage of all kinds of scientific personnel and that the electronics field is one of those in which the shortage is most severely felt. It would seem evident, therefore, that the time of those scientists we have should properly be directed toward the solution of our most pressing problems. It is not at all clear that this is being done. We spend as much time and effort on a device to inform the pilot of how much fuel he has left and what altitude and speed to fly to get home as we do on how to indentify positively a snorkel through bad sea clutter. In the former case, at the expenditure of some 150 lbs. of weight, we are providing a luxurious convenience to the pilot; in the latter case, we are dealing with a problem whose solution could mean men's lives and millions of dollars in ships and material. Admittedly, scientists are hard to coerce, and rightfully so. Better results are always achieved by those who have a deep interest in the things they are doing. I remain unconvinced, however, that the intelligence of the scientist will not respond to a plea for interest and an explanation of the importance of the end result. As an example of directed research, some years ago I set for the Electronics Laboratory a rather simply stated problem: "A submarine is at rest submerged at a depth of 500 ft. Find it." The enthusiasm and original thinking demonstrated in working on this problem has been remarkable. The solution of the problem has required considerable feet-on-the-desk consideration, a method of approach of extreme value. My reputation hardly puts me in a position to challenge Thomas A. Edison, but I wish on many occasions he had chosen to word his statement, "Genius is 20 per cent consideration, 10 per cent inspiration, and 70 per cent perspiration."

In similar view, in the next step beyond research—i.e., development—we all too often act like the proverbial cat on the hot griddle. No sooner do we produce a breadboard model of a new piece of equipment than we lose interest, throw it at the production man, and depart on new flights of fancy. This is directly contrary to the method of development which has stood aviation in such good stead for so many years. In aviation we are used to considering the first article not only as a prototype for first limited production but also as a prototype for further development. We are accustomed to wringing out the last iota of performance from an airplane model by aerodynamic redesign, more power, and better equipment before, finally, with a deep sigh, moving on to a completely new design. We are all familiar with the F-86 airplane series—for example—and the F9F series, both of which are up to their eighth or higher version with improved performance and combat effectiveness at each step. One of the Navy's latest and most important aircraft is powered with an engine I first flew with in 1929. I can see no logical reason why many electronics equipments cannot be treated in the same way. Admittedly, this has been done in a few cases, but all too often we appear deliberately to throw away the engineering man-hours and operational and maintenance experience put into a given equipment and start from the ground up to design a new one, even though the performance improvement frequently seems hardly worth the effort. This would appear to be a serious waste of that critically short raw material—development intelligence. As one approach to this problem, the Naval Electronics Laboratory at San Diego has developed a series of standard circuits that are specified wherever applicable and, being preproduced in standard packages, save design and developmental time and effort. While this particular solution to the problem might not be too applicable to aircraft electronics—the power loading of an aircraft carrier being of relatively minor interest—it does represent an approach that cannot help but simplify design, development, operation, and maintenance.

As another facet of the same problem, we frequently appear to start a new development solely for the sake of starting a new development. The performance gain in the new equipment is so minor that it does not justify the time and effort spent. On occasion, the new equipment is substantially better, but it is applied to an airplane that has little use for the added performance. For example, it hardly appears logical to double the power of a radar installed in an antisubmarine search airplane if, by doing so, you achieve the result of improving only the radar range. Since the airplane normally operates at altitudes at which the difference between 150 and 200 miles extreme range is a matter of complete indifference, the logic of such a change is certainly assailable. Such goings on remind one a little of the story of the expert rifleman who, when asked to shoot a fly a mile away, asked, "Which eye?"

Some years ago I made a plea for greater recognition on the part of the airplane manufacturer of the importance of electronics in aviation and the necessity for each aircraft designer's having a qualified electronic group in his engineering organization to assure proper marriage of the airplane and its electronic equipment. I am more than gratified to see that nearly all airplane companies now have strong electronic groups. It is essential that the manufacturer be in a position to interpret for the electronic designers the needs of his aircraft and to direct their efforts toward the joint solution of the airplane-electronics problem. He must be careful, however, to avoid the primrose path of taking over himself the design of electronic equipment for his own airplanes lock, stock, and barrel. No one airplane builder can afford to gather all the required talent under his own wing, nor can the country afford to have him do so. Competition is the spice of life, perhaps, but, for the military services, standardization is the bread and butter, and standardization is most readily achieved through design of electronic equipment by the electronics designer.

I hope I have not left the impression that standardization, simplicity, reliability, and maintainability must be considered paramount. These factors are all essential, but performance adequate to meet the requirements of the airplane's mission cannot be sacrificed to them. However, here the important words are "adequate to meet the requirements." One should never use a sledge hammer to drive a tack, and frequently the complex, exact solution can be sacrificed for the more simple approximation with no undue effect on the airplane's ability to get there and back again. Here, again, it must always be remembered that current aircraft, at least, carry a fine computer, a terminal guidance system, and a system corrector at all times in the intelligence of the man who interprets the scope pictures and pushes the buttons.

In the last 4 years we have most certainly developed better and more powerful equipments and expanded the field of electronics to cover more end uses in the airplane, but there has been only one development that offers hope of major changes in air-borne electronics. This is the transistor. Four years ago the word "transistor" was in the same class as the words "nuclear energy" in the early 1940's. Mention those words then and you were lucky if they went back only ten generations in investigating your loyalty. Now, transistor is a relatively common household word and even operates that gadget that Dutch Kindelberger switches to "off" when he is tired of listening to you. The transistor has yet to take its rightful place in electronics in aviation for a variety of reasons—the biggest of which, I often suspect, is sheer inertia on the part of the designers. While it is perfectly true that the old germanium transistor had many faults and possibly even limited application, the newer silicon transistor has eliminated many of the troubles and broadened the field of application. If its advantages in lightness of weight, reliability, and resistance to shock and acceleration were the transistor's sole claims to fame, its use should be prosecuted at high priority since in modern aircraft a

penny saved is no longer a penny earned—it is now $9.65. But those factors, while extremely important, are nowhere near as important as its major characteristic, which is the tremendous decrease in power required to operate transistorized equipments. In looking at the electrical and electronic equipment of modern aircraft I sometimes wonder if the engine power range and airplane fuselage size are not more nearly dictated by the generator output and diameter than by any other factors. This reduction in power required has an extremely important bonus in the reduction of heat developed in the equipment and in the airplane. At the speeds we are proposing to fly, we hardly need an additional source of heat to be disposed of—the airplane will be warm enough.

While perhaps an extrapolation of the normal airplane electrical power required curve, it might be interesting to note the generator capacity of the WV-2, the Navy's early warning aircraft. This airplane requires 60 kva. of a.c. power plus 2,000 amp. at 28 volts of d.c. power. It is true that much of the equipment in this airplane is not subject to the use of transistors, but enough is to make adopting this approach well worth while.

As a matter of incidental interest, the WV-2 represents a case of adaptation of an existing airplane to a specific military mission with the close cooperation of the electronic designer and the aircraft manufacturer. The first prototype, the WV-1, was delivered to the NADC, the major developer of the electronic equipment, almost exactly 4 years ago. The latest version, the WV-2, a Super Constellation, clearly shows the results of 4 years of cooperative effort, even though it could still stand improvement. The concept of the early warning aircraft, the flying combat information center, has proved highly successful and has received general acceptance in both the Navy and the Air Force.

Many other attacks on the weight problem have been made in the form of printed circuitry, miniaturized components and tubes, and the like, by all the industries and have resulted in substantial weight decreases and improved form factors. One of this type is the development of quartz and, subsequently, fused silica delay lines by the Electronics Laboratory of the NADC as a replacement for mercury at ultrasonic frequencies. Moving target indication would hardly have been practicable for air-borne radar without this development in view of the weight and size of the mercury delay line.

Many improvements in reliability have been achieved through the use of magnetic amplifiers instead of tubes in servo-loops, of printed circuits, of the so-called "tinker toy" techniques, etc. The use of these devices and of potted circuits has markedly improved maintenance problems as well as reliability under the stresses of aircraft operation. The Navy's problems in this regard are especially severe, of course, because of the necessity for catapulting and arresting carrier aircraft. As a matter of interest, with respect to the problems of acceleration and vibration, one of the devices developed to aid in the solution of these problems is now one of our worst headaches. The standard ANA connector is an awesome thing, indeed—large, massive, and impressive. It has done a good job of maintaining connector integrity in past years. However, the sight of some of the modern black boxes with these large excrescences attached to them amuses the casual observer and discourages the designer. It is not at all unusual to see a black box or component hardly larger than a pack of cigarettes, with a connector almost the size of an orange.

Much has been done in the way of packaging equipment and reducing its size and weight to make the airplane designer's job easier. In one field, however, a critical situation still exists and may always exist. This is in the matter of the size, shape, and location of antennas. In the field of communication antennas, this problem can be solved through close cooperation of the airplane designer and the antenna expert, with particular emphasis on model studies and research and development using actual antennas in the presence of true reproductions of surrounding reflecting surfaces.

In the field of radar antenna, however, the situation is quite different. Because of the absolute necessity of increased radar ranges in modern high-speed aircraft, higher effective propagated power is a must. To the radar designer, the answer is simple. Since twice the antenna size is the equivalent of four times the magnetron power, he would, of course, choose the larger antenna even were the larger magnetron available, which it frequently is not. The airplane designer has a more critical problem, however. He would like to have the cake but eat it, too. He lives in the hope that some kind fairy will have a magic wand (nuclear energy powered) which will require him neither to add another keg-sized generator to the electrical generating system nor to attach his airplane to an outsize tiddlywink. Those of you who have seen the early warning airplane —with its 18 ft. wide, 30 ft. long, and 6 ft. deep radome on the bottom and the 8 ft. high, 12 ft. long, and $4\frac{1}{2}$ ft. wide vertical radome on the top—will know that I am not exaggerating. There seems no ready solution to this problem except the utmost cooperation among the operator, the airplane designer, and the electronics man in the determination of the radar range actually essential to the mission of the airplane and how that range shall be obtained.

Somewhat earlier I remarked on the fact that some of the less glamorous jobs in electronics and aviation have not been given the attention that is due them. One such large area is the field of electronic countermeasures. The military man's existence is largely concerned with the continuous interplay of attack and defense, measure and countermeasure. An electronically quiet missile, airplane, or ship may be difficult to see and combat, but neither can such a vessel see where it is going. The chances are excellent that it will be electronically active, in which case it can be detected, intercepted, and duped. Even if it is using some passive

(*Continued on page 76*)

Past and Present Automatic Flight Control Development

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Introduction

THE MILESTONE OF POWERED FLIGHT was passed more than 50 years ago, and about 40 years have elapsed since the demonstrable "stable aeroplane" of Lawrence Sperry. This latter milestone of stable flight never stays far behind because of the tremendous advances in aircraft characteristics and the continued demand of different and harder-to-meet stability and control requirements. The basic assumption of much research and development work is that aircraft stability is available and that suitably designed control devices may be "attached" to satisfy requirements such as pilot relief or navigation assistance. This assumption is frequently invalid because the stability and control problems, although integral, tend to be incongruous, necessitating that the controls designer carefully consider his applications as a key factor in more than one stability loop. The successful solution of the control problems of yesterday's aircraft is little guarantee of success for today's aircraft, and certainly these same previously successful solutions will fall short if an attempt should be made to apply them directly to our future types.

As an illustration of this inescapable advance I recall that, back in 1947 when I had the opportunity to work on the fondly called "push-button airplane," frequent presentations were given both as an information service and to help "sell" the concept of completely automatic flight control. However, one of the ground rules for the close of any talk was to caution the listener that push-button, point-to-point flight for piloted aircraft was at least 10 years off for any operational application, either military or civil. This pessimistic note was included to dampen any overenthusiastic selling that might have been done. Now, 7 years later, it seems that our 10-year prediction was optimistic not pessimistic. I am sure that with devoted effort we could have perfected this automatic flight control system, but, during these 7 years, aircraft advances would have left us few places for its application.

This advance in aircraft characteristics engenders by its success the requirement for continuing research and development in the controls field. Tools such as analog computers have greatly enhanced the controls research picture. They are a fine complement to the flight research so necessary to prove the assumptions or verify the "answers" before committing to development. We of the Wright Air Development Center have the motto "Fly Before You Buy." This maxim is the precept for the tremendous amount of flight testing and evaluation work conducted in support of the development activity. "Fly Before You Buy" may also be applied to many investigation and research programs preceding development. Flight investigation can head off unrealistic development or furnish the logical line of attack for a component or system engineer as well as be used as a generating or stimulating source of new ideas. The point-to-point or push-button automatic flight control program, although never accepted as a totality, has by its flight research efforts served to stimulate the development of individual automatic control subsystems such as automatic radio-beam sensors, automatic navigation devices, and single-lever engine controls. It is one of these subsystems in the automatic flight control program which I should like to discuss. At the outset of the program an effort was made to analyze a flight and to break it down into the logical operations such as take-off, cruise, landing, etc. An attack could then be made on converting the discrete functions of each operation such as throttle control, the raising and lowering of flaps and landing gear, and the selection of and operation on various navigation systems into an automatic operation. The next necessary step was the coordinating of the operation of these controls through a central control called a master sequence selector. This device allowed programing of the automatic devices and functions as required during each flight phase.

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* Assistant TRACAL System Officer.

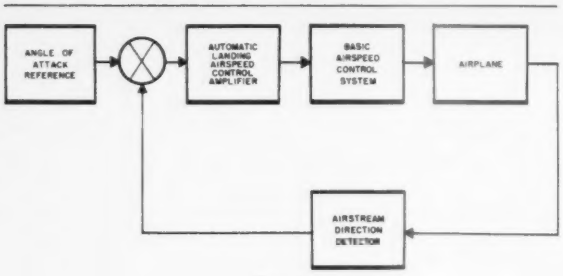

FIG. 1.

AUTOMATIC LANDING AIR-SPEED CONTROL

In the experiments with point-to-point automatic flight, control of the air-speed parameter was found necessary during the critical landing sequence. Neither the programed fixed power settings nor the rudimentary air-speed control systems used were found to be totally adequate. The development of the landing air-speed control system was an attempt to get a research tool by which other techniques of controlling speed during landing could be investigated. The landing air-speed control system, like the other components of the all-weather automatic flight control system, was designed to operate completely automatically from programed commands or semiautomatically from commands given by an operator. The system was intended to supplement the basic air-speed control system and other automatic flight control equipment in providing a satisfactory air speed during approach and desirable thrust control during flare-out. When using the control, the landing air speed of the aircraft is adjustable as a percentage of stall speed, and the air speed that is established is compensated automatically for gross weight and wind conditions. The basic requirements placed on this subsystem were the establishment of a safe minimum air speed for the aircraft from approach to touchdown and the control of engine thrust during flare-out in a manner to achieve a safe landing. Also incumbent on the design of this system was its proper integration with existing automatic approach and flare-out equipment and with a basic air-speed control system operating the aircraft throttles through a single-lever engine control system. As with most experimental devices or research tools, flexibility of use was a keynote in the overall design. Modes of operation of this control as well as in the other control subsystems of the all-weather flight control system were variable, and the loop gain settings could be adjusted (Fig. 1).

DESIGN PRINCIPLES

The design of the landing air-speed control is based on the principle that the stall angle of attack of an aircraft is largely independent of the aircraft's gross weight and flap configuration. If during approach and landing an angle of attack slightly greater than the stall angle can be selected and maintained, safety from stall is assured, and the average thrust value derived depends upon the existing gross weight and flap position (Fig. 2). The use of angle of attack as the basic control criterion for setting approach air speed assists to fulfill the two basic requirements previously mentioned—namely (1) the establishment and maintenance of an approach speed sufficiently high to ensure safety from stall under any likely wind condition and longitudinal maneuver and (2) the establishment and maintenance of as low an approach air speed as possible to minimize landing roll required, tire and brake wear, and ground control problems. The angle of attack sensing element selected measured the airflow relative to a fixed axis in the aircraft with an accuracy of 0.1° and a response of 0.07 sec. in the range of air speeds covered by the landing air-speed control.

A sidelight on the angle of attack sensing element should be mentioned at this point. Over and above the implicit requirement for accuracy and a proper dynamic response is the requirement for proper location on the aircraft. A boom projecting from the nose of the aircraft, although obviously best, would not be a representative installation for high-speed military aircraft. A suitable compromise location was found on the fuselage which afforded a region of constant airstream direction and which had the local airflow direction unaffected by the propellers, flap position, extension of the landing gear, or other projections from the surface of the aircraft.

CONTROL SYSTEM

Using the basic philosophy of allowing angle of attack to command the air speed, the control system was established using the elevators to control altitude or the vertical position with respect to a glide slope beam and the throttles to control air speed or angle of attack. In one case—the alternate mode—the throttles are driven directly from angle of attack error information. In the other case—the normal mode—the throttles are driven indirectly by using the time integral of angle of attack error to command the basic air-speed control system reference. The dynamics of a loop controlling angle of attack and a loop controlling air speed are about equal; however, other factors are worthy of note. The angle of attack loop requires less equipment, has inherent pitch anticipation, and has a faster response to changes in angle of attack reference; however, the air-speed reference control loop has a higher signal-to-noise ratio in

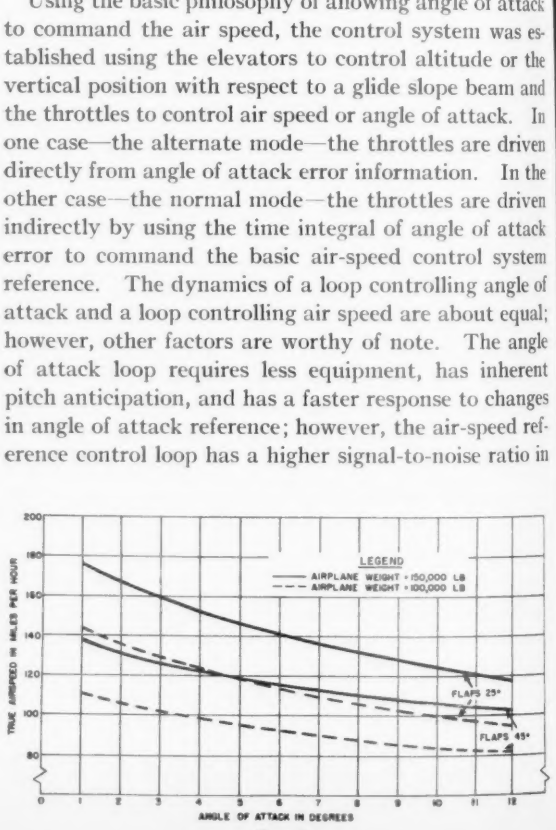

FIG. 2.

rough air, and the use of a gust compensator circuit is more easily included. The control of the air-speed reference by the angle of attack must be slow with respect to the response of the air-speed control itself to achieve stability. In this design the rate of change of the air-speed reference was made proportional to the angle of attack error. This enhanced the stability of the loop, and the integrating action put a desirable filter on the angle of attack signal to achieve the higher signal-to-noise ratio. Both basic modes of control were satisfactorily investigated on an analog computer and by flight research prior to hardware construction.

Additional Control Features

Several additional features were found desirable for inclusion in the landing air-speed control system. Turbulence has always been a trial to stable flight control. Gust disturbances on the final approach path are particularly detrimental because of the aircraft flying close to the stall point. To effect the same safety margin from stall which is obtained in calm air, it is necessary to use a higher speed. To select too high a value, however, reduces the safety margin desired because of increased landing speed. The optionally selectable gust compensator circuit included in this system measures the difference between the angle of attack peaks caused by gusts and the average value of angle of attack. This difference is then added to the instantaneous value and the sum used to control the air-speed reference. The signals are added in such a way as to increase the average air-speed reference by a value proportional to the magnitude of the peak gusts encountered. In this way the angle of attack peaks are made to occur at the preset reference value of a per cent of stall speed. When no additional gusts are met, the gust compensator signal decays at a predetermined rate returning the air-speed reference to its originally set level.

During the landing phase of flight, power reduction is desired for various reasons: to achieve proper trim for a satisfactory landing attitude, to reduce the lift to prevent "floating," and to shorten the landing roll by decreasing the forward velocity. Immediately prior to touch-down, it is desirable to close the throttles to the low-limit stop. At a preselected height a few feet above the runway, a throttle cut-back is initiated in the landing air-speed control with the rate of throttle closure adjustable by means of a tap switch.

In many types of aircraft, under approach conditions an appreciable change in lift occurs when a change in throttle setting is made. This is particularly true of multiengined propeller-driven aircraft. This effect causes undesirable interaction between the glide slope path control loop and the air-speed control loop. During the flare-out portion of the approach this effect becomes a definite problem because of the throttle cut-back. The cut-back reduces power, and the resultant loss of lift causes a path transient that may be detrimental at touch-down. Pitch anticipation was built into the landing air-speed control to combat this condition

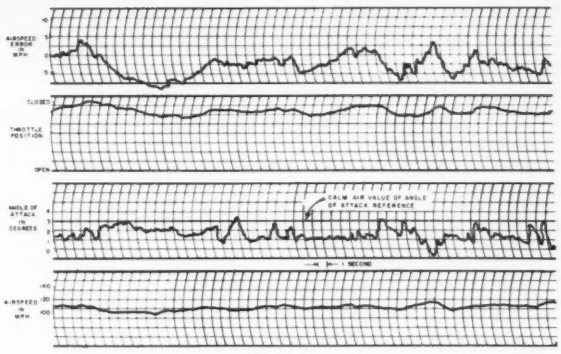

Fig. 3.

by cross coupling a throttle position signal into the pitch axis input of the automatic pilot. In this manner and by adjustment of the circuit gains, the aircraft increases its pitch attitude sufficiently to maintain constant lift when the power is reduced.

Flight-Test Results

Flight testing of the landing air-speed control demonstrated satisfactory performance in a system where measured angle of attack is used to set air speed. Successful operation of the gust compensator is shown in Fig. 3. The feasibility of the pitch anticipation and throttle cut-back were also demonstrated by actual flight tests. The pitch anticipation function permitted an automatic approach to be made under air-speed control with less deviation from the glide path beam than had previously been possible without this feature. Combined operation of throttle anticipation and throttle cut-back during flare-out permitted an automatic landing to be made in a satisfactory attitude with a reasonably slow touch-down air speed.

The landing air-speed control's capability to maintain a constant safe angle of attack in the presence of large disturbances was demonstrated in an approach during which the wheels were lowered and the flaps were extended, first to half-flap position and then to full-flap position. Each of these major additions to the drag of the aircraft caused only a smooth decrease in air speed while constant angle of attack was maintained.

Another significant result obtained during the flight tests was successful control of angle of attack by the throttles, the alternate mode of landing air-speed control operation. This mode of control is important for two reasons. First, thrust control can be achieved by such a system with simple equipment and independently of any other air-speed control or air-speed reference system. Second, such a system could be used to fly automatically at an angle of attack yielding the highest lift-to-drag ratio for maximum range in cruising flight.

Conclusion

The automatic landing air-speed control system development and flight-test program has shown that it is feasible to set the landing air speed of an aircraft by

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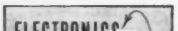

Automatic Flight Control Requirements

FRANK R. COOK*

Minneapolis-Honeywell Regulator Company

THE AVERAGE SERVICE PILOT pressed into wartime service fresh from management duties, from reserve status in civilian life, or from training, thrown into a confused and fast-moving combat situation involving all-weather round-the-clock combat operation in supersonic aircraft, will be up against an extremely difficult task.

He will rapidly have to become acquainted with his operational type of aircraft and its mission and develop his capabilities to the maximum extent possible. In order that these capabilities be adequate for the mission, it is the present job of the contractors to the armed services to supply him with combat aircraft that are designed and equipped to take maximum advantage of the pilot's capabilities and yet appreciate his limitations. All-weather flight at high speeds and high altitudes on extended missions, each difficult and varying from day to day, indicates the need for furnishing the combat pilot with automatic control and guidance equipment to assist him in the accomplishment of these missions.

The word "requirements" is used in the technical rather than the military sense, it being fully recognized that the military must establish and control their requirements and are the only ones in a position to do this. However, it is generally recognized that the conceptual stage of these military requirements must include the careful review of technical analyses that indicate the capabilities and limitations of manual control for a given application, and the capabilities, weight, space, and complexity of automatic controls to do jobs beyond the capabilities of the human operator. This latter analysis and review must be accomplished with the help of the technical groups who will be responsible for the development and the product design of the equipment. The need for automatic controls may be dictated by the performance requirements or complexity of a given task or by the accumulation of tasks required of the human operator.

The continued development of manned aircraft of ever-increasing capabilities paces the need for the greater development of flight control and guidance equipment which will allow the operational accomplishment of all-weather missions beyond the capabilities of the unaided pilot, yet take full advantage of his capabilities. The development objective for control equipment in manned aircraft should not be to replace the pilot—this should be left to guided missile designers—but these controls should be designed for minimum complexity to do things that the pilot cannot do by reason of the high performance characteristics required or the multiplicity of tasks that must be performed simultaneously.

The high speeds and altitudes of the supersonic interceptor, the fighter-bomber, the helicopter, and the vertical riser, and the wide attitude requirements and limited stability of these types, coupled with the greater accuracy requirements for both offensive and defensive aircraft which are dictated by nuclear weapons, present the greater challenge to the automatic controls design teams.

Note the three major phases of combat flight: navigation, strike, and landing. Besides the basic control and guidance equipment required for these phases, engine controls, fuel range and endurance indications, accessories for instant pilot's control inputs, constant altitude and Mach controls, climb and descent controls, air-frame damping equipment, acceleration and maneuver limiting controls, the proper integration of these systems, and the necessary integration of them with cockpit instrumentation are involved.

The important areas of "routine" automatic flight of commercial aircraft and the related difficult objective and subjective problems of reliability and crew acceptance are not touched on here. Undoubtedly military developments in advanced areas will contribute directly to the state of this art as it progresses and to the momentum involved in the acceptance of the necessary devices.

Presented at the Flight Control Instrumentation Session, Twenty-Third Annual Meeting, IAS, New York, January 24–27, 1955.

* Formerly, Director, Aeronautical Division, Research and Planning, Minneapolis-Honeywell Regulator Company. Now, President, Frank R. Cook Co.

During the navigation phase of flight the transonic and supersonic aircraft will probably need control equipment that will augment the stability of the basic air frame and dampen pitch and yaw oscillations. Control stick steering provisions are needed to allow the pilot to put his commands into the system in a natural manner and to override the automatic controls whenever he desires; provisions are needed to hold automatically a Mach Number or altitude and heading and in some cases to provide terrain clearance control. Completely automatic en-route navigation, either by inertial or wave propagation means, is needed to ensure the completion of all-weather missions by single-seat airplanes. These are also needed to coordinate missions, control traffic, avoid collisions, and provide data for position reports. Ground control signals must be accepted.

The strike phase of the flight may simply be the end point of a precise, completely automatic navigation mission, at which point armament stores are automatically released either in level flight or during a programed or controlled maneuver; it may be the start of a run on the target on the ground by use of the bombsight and the automatic flight of the airplane by use of bombsight tie-ins. For interceptor aircraft it may be the start of the search for the air-borne target by use of air-borne radar, the automatic tracking of the target when found, its interception and the automatic release of armament stores against the target, and the automatic breakaway from the strike.

For the landing phase of the flight, controls are needed for traffic and for the precision touchdown, and for the transition phase between the two. These should accommodate aircraft approaching at various speeds and altitudes, and should be as flexible as possible. Flexibility is also of great importance for the precision landing phase in various types of aircraft, so that various wind conditions and varied spacing of incoming aircraft can be coped with and maximum utilization of the airstrip still be obtained. Precision landing equipment should be capable of handling either straight-in or curved approaches. In this manner the time spacing of aircraft touching down can be kept as small as possible. Various types of aircraft approaching at various speeds can be brought in on tight or on loose curved paths so that touchdown intervals are kept constant and maximum strip utilization results.

There is a common frame of reference for the control problem. Broken down into its basic elements the problem is to sense, then, as a rule, to amplify the sensed signal, then to compute the desired action, then to perform this action.

(*A*) *To Sense:*

Pickups are required to give the various required physical measurements; motion, both linear and angular (in rate, acceleration, and displacement), for the complete navigation problem, fuel quantity and the direct or indirect means of determining flow is necessary; free air-stream and engine gas flow data are needed—to give direction, velocity, temperature, and pressure.

(*B*) *To Amplify:*

It is often necessary to sense with minimum reaction—for example, effect on gyro drift due to pickoff friction and on airflow direction due to probe effect. Weak signals result and must be amplified.

This is usually done electrically with requirements for minimum weight, space, and cost, with greatest reliability, and with minimum dependence on the stability of the source of amplifier power.

(*C*) *To Compute:*

Coordinated, stable control requires the neat integration of input sensings and output command signals. This is computed either mechanically or electrically, with minimum complexity, maximum reliability and flexibility, and minimum weight, space, and cost.

(*D*) *To Actuate:*

Actuators or servos—either electric, hydraulic, or pneumatic—must be adapted to the requirements, and must meet performance needs of the system with minimum weight, space, and cost.

Basic components for these control systems have gone through several generations of development in the last 15 years. The rate of their development is probably more rapid now than at any other time in the past, and the requirements for this rate of development are continually mounting. Sensors (including gyros), computers, and servos are the basic elements. As for sensors, there is a continuing need for a better device to measure the relative position or movement between a gyro and its associated equipment with minimum reaction force transmitted to the gyro in the form of flux reactance or friction of a potentiometer and with maximum resolution. These devices must be able to withstand shock, vibrations over a wide frequency band, high accelerations, and be suitable for use over a wide temperature band, especially at the high temperatures encountered in supersonic aircraft. They must be reliable, have long life, require minimum maintenance, and be reasonably easy to manufacture to the precision required.

Gyroscopes that sense rate of movement and position, either directly or by the integration of rate signals, and which are smaller, lighter, less costly, and easier to manufacture and maintain, are in continuous demand. From a product design viewpoint the basic gyro problems are bearings and sensors. Bearings that have much greater life, less friction, less internally generated heat, and can be operated at much higher revolutions per minute present a great challenge and represent a very pressing need. With all due respect to the good bearing work that has been done, the state of the art here is far behind needs. Satisfactory instrumentation is not available to determine exactly what exists in a given design or what progress is being made in a given research or development program.

Basic amplification elements are normally the vacuum tube, the transistor, or the magnetic amplifier. Each has its limitations. The vacuum tube has a

relatively low overall efficiency factor, limited structural strength of its elements, and greater size and weight compared to the transistor. However, its high gain and fidelity, especially at the higher frequencies, is unmatched by the other elements, and structurally sound designs are entirely possible. Initial air-borne production equipment that includes transistor amplifier elements is just being delivered. A great need exists for production transistors that will withstand the considerably higher temperatures encountered in installations in supersonic aircraft and in high compartment temperatures encountered by engine controls. The small weight, space, and power requirements and the resulting low heat rejection problems of the transistor are unmatched by the other amplifier elements, and it probably will be used almost exclusively for air-borne controls when produced in quantity for high ambient temperature applications demanding great reliability. The magnetic amplifier has limitations of frequency response, and is the heaviest and bulkiest of the three unless great care is taken in its design. It suffers from high temperature problems, like those that the transistor encounters, due to the characteristics of currently available rectifiers.

The majority of the computers in the past have been of the analog type. However, the digital type is rapidly approaching the point in its development where space- and weightwise it can be considered seriously for production air-borne applications. The designer and the systems manager are faced with something of a dilemma in the use of the digital computer. Its great capacity for computation services allows it to be used for the computing needs of several systems by the time-sharing of the computational circuits. However, when several systems are tied together so as to be dependent upon a common component, especially one as vital as a computer, the overall reliability and vulnerability of the system suffers. This leads to the demand that the digital computer be extremely reliable. Project offices approving specifications must carefully review and analyze the state of the art with respect to any particular application to be sure that these reliability requirements can be met in the final production device.

Servos are used to perform actions as instructed by a computer at the speed and with the stability dictated by the system requirements. In World War II flight control servos with a frequency response considerably less than 1 cycle per sec. were entirely adequate for the needs of the air frames controlled. With the current generation of production and development supersonic aircraft, frequency response requirements from 5 to 40 cycles per sec. are common. Power requirements have risen from one manpower to several horsepower per servo. As a result, hydraulic servos are in general replacing electric servos, as a higher frequency response is readily attained and higher horsepower can be developed with low weight and space. Two of the basic problems being encountered as a result are the effect of foreign particles—even minute—in the hydraulic fluid, on the performance of the hydraulic control valve that directs the flow of fluid to the two sides of the hydraulic ram at the proper times, and the effect of very high ambient temperatures on the hydraulic system, including the fluid itself. Such valves also present major production problems—particularly the maintenance of machinery tolerances much tighter than heretofore encountered in this kind of equipment. There is a pressing need for designs that are less sensitive to foreign particles and which are more producible.

Much research and development and production design effort must be completed in these areas. Great progress has been made in the last few years, especially in the area of hydraulic control values and gyros of the floated variety. Components are needed and are in existence which were unheard of a few years ago.

It is no longer possible to design these systems by anything approaching intuition. A most extensive analysis and analog and digital computation of many flight conditions and many, many combinations of design parameters must be analyzed in order to develop equipment that will be able to meet the needs of the air frame and its mission and will be of a configuration approaching the optimum with respect to the design requirements of each component and the integration of the overall system. Almost 50 flight conditions are analyzed in the latest supersonic aircraft flight control system studies. This is at least five times the amount of analysis necessary 5 years ago.

Longer range research programs and better staff work in determining requirements and in establishing research and development programs, both in the military and in industry, are stabilizing these activities. Research and development personnel in industry are probably in a better position to see technical trends in these areas—they are working full time in them; military personnel are in the position to establish requirements as the state of the art advances. Better procedures are needed for the exchange of views between the two, so that industry effort is continually placed on lasting problems of the military with the result that these problems are solved as rapidly and as effectively as possible.

In considering the problems of developing requirements and developing designs to meet them it should be recognized that supersonic flight problems may unfold at three to four times the rate of the problem of controlling the fastest commercial air liner.

World War II autopilots performed two functions, tie-in to the bombsight and stabilization of the aircraft, for a weight of about 150 lbs.; the latest military autopilot system performs twelve functions for a weight in the neighborhood of 60 lbs. Much progress has been made, yet many problems are unsolved.

Additional functions must be performed by flight control equipment; reliability must be continually improved; equipment that will withstand the much higher temperatures encountered in supersonic flight must be fully developed; a program of training per-

sonnel to use and maintain this complex equipment must be greatly accelerated.

These instruments are being developed at a rate of a new generation every 3 to 5 years. Once developed to perform all functions they will undoubtedly go through a whole generation of development for additional miniaturization, weight-saving, and producibility, and at least another generation for reliability improvement.

Turning from the hardware to the management viewpoint, one of the basic problems in establishing research and development programs, especially of this nature, and the very obvious one, is to maintain a proper balance between the two. Probably few people realize that of every dollar appropriated by the Government for research and development, hardly six cents is spent on research, the rest is devoted to the development of hardware in the form of experimental aircraft, missiles, and their components. The dual phrase, "Research and Development" has assumed a singular meaning. In conversations the thought of research is too often remembered while the thought of development may get dim. In practice the budget emphasis is 16 to 1 the other way around. This mere fact in itself would not be significant unless there were ample reason to believe that complete weapons are not being developed without a previous orderly program providing adequate research information.

The result of an unbalanced research and development program and policy is hardware that does not work as it should. The need for additional research information becomes glaringly apparent, and the placing of emphasis on problems of getting it is automatic. However, from a program and budget viewpoint the question here is, "Could this not have been forecast in advance and properly provided for?" This question again revolves around the point of the management concerned having complete and sympathetic understanding of the research and of the development processes—management, both military and industrial.

It is always difficult to sustain the support of an operation that requires many people and many dollars and whose output is information—paper, in other words—rather than weapons in the hands of troops or goods on the shipping dock which make the cash register ring.

The processes of solution of this planning and programing problem obviously involves a period of many years and much trial and error. However, the state of this art has been developed to such a point that it should be possible to do a better job in the overall.

One of the mental pitfalls that is encountered here results from the fact that research organizations are more or less by definition a minority organization, even in operations where it is strongest. Its population probably will not exceed one out of fifty in an integrated Research, Development, and Production; or Research, Development, and Operations organization. This places a heavy burden on research organizations in properly presenting their views and in the staying power required to maintain these views over a long period of time. They must avoid the pitfall of becoming apologetic or defensive about their operations, must be entirely objective and competent, and, where programs are obviously of an exploratory nature with no reasonable possibility of the planned end point being guaranteed to arrive on schedule, of clearly stating the real nature of their proposed program and the needs for it even though it may be tenuous in some respects.

As it is much easier for next steps in research programs to be seen clearly by the research groups working on the problems in industry, governmental contract administration procedures should be modified to allow the latitude necessary to cover the budgets needed by industry research groups to pursue the needed work.

In conclusion, while recent progress has been great, a large job faces the aeronautical electronics and controls industries in fulfilling the military needs for automatic flight controls for current and future manned aircraft. It is to be expected that at least three generations of equipment and 10 to 15 years' time will be needed to complete the job that can be seen now.

Changes of Address

Since the Post Office Department does not as a rule forward magazines to forwarding addresses, it is important that the Institute be notified of changes in address 30 days in advance of publishing date to ensure receipt of every issue of the *Journal* and *Review*.

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Automatic Flight Control in Air Transportation

M. GOULD BEARD* AND PERCY HALPERT†

American Airlines, Inc., and Sperry Gyroscope Company, Respectively

Introduction

One fascinating aspect about aviation is the frequent and sometimes startling opening of new fields of development which challenges the best in engineering ability. We have already entered the jet era, and now find ourselves engaged intensively in the process of refining, perfecting, and adapting many mechanisms and devices used on earlier, slower airplanes to the requirements of these new high-speed transports.

Automatic flight has been an exciting consideration ever since Lawrence Sperry won the French contest in 1914 for a safe airplane equipped with an automatic pilot. The automatic pilot became a factor for serious consideration in transport aviation when it was first installed in the Boeing 247 in 1934. Automatic approach became an intriguing possibility during the long series of trials that United Air Lines, Inc., conducted at Oakland during 1938–1940 with the A-3 vacuum automatic pilot. The possibility became a probability with the development of the postwar electronic automatic pilot. But before it became dependable and usable in transport aviation, automatic approach still had to await improvement in the ground equipment, the localizer and glide path, and also the more perfect matching of the air-borne units to the control characteristics of the airplane. As in many other necessary devices now in common use, the automatic pilot has traveled a rocky road in its development through the past years to arrive at its present state of refinement and acceptance by the air lines.

This does not mean that the air-transport industry has even yet completely accepted the automatic pilot as a profitable and necessary device for efficient operation of transport planes. Manufacturers and proponents of automatic pilots in the air-transport industry still have a selling job ahead to convince some operators that the automatic pilot can pay its own way and provide a direct return in dollars to the operator.

There have been many articles and papers written through the past years which have described the application and purpose of automatic flight control in air transportation. These papers have dealt thoroughly with the value of the automatic pilot in reducing pilot fatigue, improving safety, and giving a generally more comfortable flight to the passengers. The addition of automatic approach, in particular, has increased the usefulness of automatic flight control tremendously, and some air lines have reduced their operating minimums with this new aid.

It is not the purpose of this paper to dwell upon these facts, which are fairly well known and generally accepted. There is still one aspect of the value of automatic flight control, however, which has not been considered until recently and which holds forth the possibility of additional direct economic savings to the airlines. This paper will present some data on American Airlines' nonstop coast-to-coast flights which indicate these savings. It will also present the automatic flight control performance that has been obtained in the DC-7 and will discuss new requirements necessary to obtain desired performance in high-speed, turbine-powered aircraft.

The main economic saving that has been considered thus far is that which results from improved schedule regularity brought about by approaches and landings under lower weather minimums. There has been little doubt of the ability of automatic flight control to extend flight operations to lower minimums, to 200 ft. for the present perhaps, but eventually to zero ceiling and visibility. The direct return in dollars which can be realized from such extended operations is difficult to measure and may not be significant when compared to such overall benefits as improved traffic conditions, safety, passenger good will, and public acceptance—to say nothing of the probable increase in the use of air transportation by the public when schedules can be maintained in any kind of weather.

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† Engineering Director for Aeronautical Equipment.

Economics of Cruising Flight

In marine transportation, automatic steering has been in use for many years. In this field it is well recognized that the automatic pilot can steer a straighter course than the quartermaster in the wheelhouse—enough straighter perhaps so that the distance saved, together with the lower fuel consumption, more than pays for the automatic steering equipment. Although for years everyone having anything to do with the flight end of an airplane has observed that the automatic pilot flew a straighter, more level course than the manual pilot, the savings resulting have never been adequately analyzed and evaluated from factual recorded data. Recently some attempts have been made to record and evaluate the paths made good on DC-7 transcontinental nonstop schedules flown with and without automatic pilots. Although the analysis of much of the latest recordings is not complete, certain trends are indicated and support other recordings of more limited scope. The following paragraphs will discuss the economics of the automatic pilot with respect to straightening of flight paths, shortening of distances, and reduction of flight times. Supporting data are taken from two separate recordings and actual logs of transcontinental nonstop flight times of the DC-7.

In October of 1954, Arthur E. Jenks of the CAA made available a recorder and accompanied several transcontinental nonstop flights. He obtained a recording of flight paths showing deviations in heading only on portions of the nonstop flight flown manually and with automatic pilot. The results derived from these recordings are shown in Figs. 1, 2, and 3. The period of time covered is 5 hours.

Fig. 1 plots percentage of cruising flight time, during which heading errors were maintained, against the magnitude of the heading error in manual flight. As an example, for 24 per cent of the time there was a heading error of 2°.

Fig. 2 shows the number of times heading errors of specified magnitude were recorded during 5 hours. For example, 3° heading changes occurred 79 times in the 5 hours.

Fig. 3 shows the total time in minutes during which rates of heading changes were maintained. For example, 6° per min. heading changes occurred for about 32 min. during the 5 hours.

These three charts show what occurs during manual operation of the airplane. The record of a similar flight on automatic pilot shows that heading changes occurred only when the pilot purposely changed course.

The charts show only the lateral deviations. They cannot be used to evaluate speed differentials between manual and automatic pilot operation, since several of the essential factors are missing. The recordings do show what is happening to the heading and give an indication of what an automatic pilot can save. Probably the largest factor missing from the recordings is the effect on air speed. When the plane is flown manually, corrections for small deviations are usually made with a slow skid and with the wings level rather than with a coordinated turn. The passengers do not feel such turns or sense them in any way. Such small angles of yaw held for an appreciable time have some effect on the air speed, as the fuselage and fin drag is greater than when the plane has no yaw. We are attempting to evaluate all the factors that affect air speed from test, but at this writing the figures are not available.

The DC-7 nonstop transcontinental operation was started with automatic pilots inoperative. After about 2 months, the automatic pilots were progressively activated over a period of several months. Throughout the installation period, there were flights flown by airplanes over the same routes, at about the same altitudes, through the same air masses, at the same cruising power, with and without automatic pilots. After careful comparisons of all factors, it was possible to pick out 29 pairs of flights with and without automatic pilots, each pair being flown under generally the same meteorological conditions and over the same routes at similar altitudes and maximum cruise power. Table 1 shows the results of this comparison.

Net saving westbound:

$$+113/17 = +6.65 \text{ min.}$$

Net saving eastbound:

$$+69/12 = +5.75 \text{ min.}$$

Average:

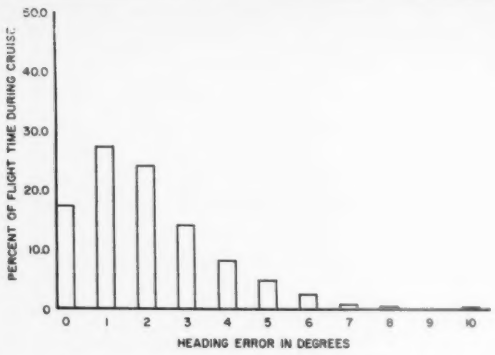
$$(6.65 + 5.75)/2 = 6.20 \text{ min.}$$

This comparison shows an average of 6.2 min. saved per transcontinental nonstop trip by using the automatic pilot. On shorter trips flown by the rest of the DC-7 operation, the saving would be less because the cruise time is shorter. Assuming that the average saving on the rest of the operation is half that of the transcontinental nonstop, the annual saving in dollars—using direct operating costs only and neglecting a possible saving in indirect cost—is $250,000 by using the

Table 1

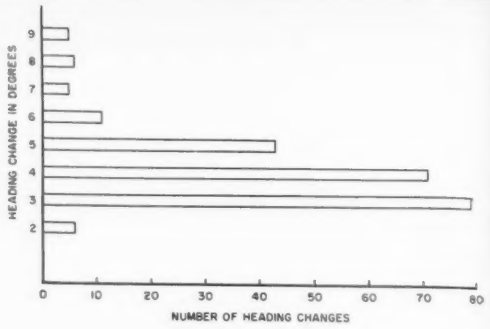
Westbound Flights		Eastbound Flights	
Date	Time Difference	Date	Time Difference
6/21/54	+7	6/18/54	−1
6/28	+7	6/19	+11
7/1	−10	6/21	−7
7/3	+2	6/30	+28
7/8	+1	7/5	+1
7/10	+3	7/7	+3
7/11	0	7/8	−3
7/12	0	7/9	+16
7/13	+2	7/12	−5
7/14	−9	7/20	+27
7/16	+27	7/22	+2
7/17	+35	9/18	−3
7/25	+17		
7/26	+6		
7/30	−11		
9/22	+11		
9/24	+25		

Plus (+) indicates shorter time in minutes with automatic pilot.
Minus (−) indicates longer time in minutes with automatic pilot.



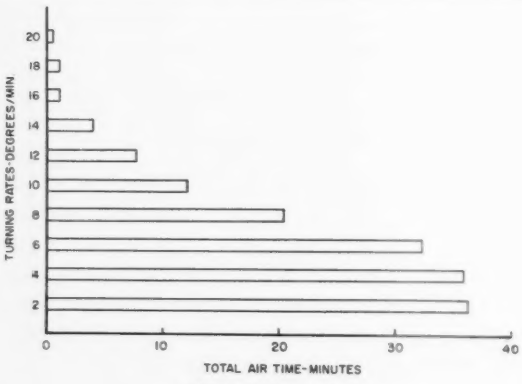
HEADING ERROR FOUND ON REGULARLY SCHEDULED TRIP

FIG. 1.



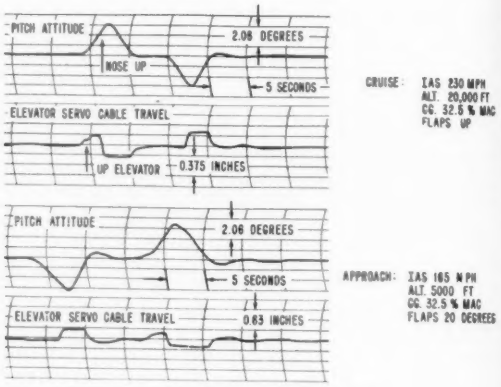
NUMBER OF TIMES
HEADING CHANGES WERE MADE
ON REGULARLY SCHEDULED TRIP

FIG. 2.



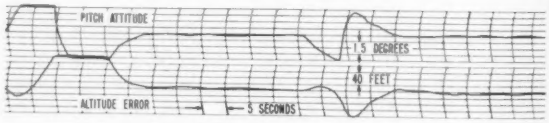
AIRPLANE TURNING RATES
ON REGULARLY SCHEDULED TRIP

FIG. 3.



PITCH AXIS PERFORMANCE IN DC-7

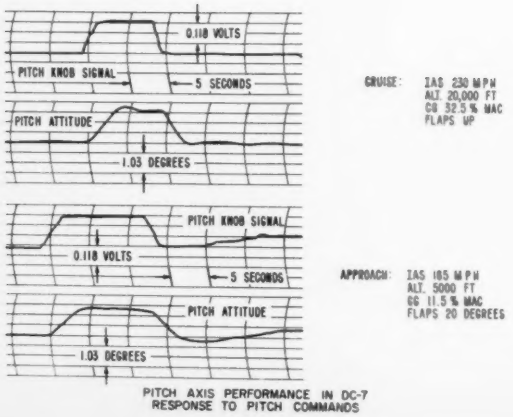
FIG. 4.



CRUISE: IAS 230 MPH
ALT 20,000 FT
CG 32.5 % MAC
FLAPS UP

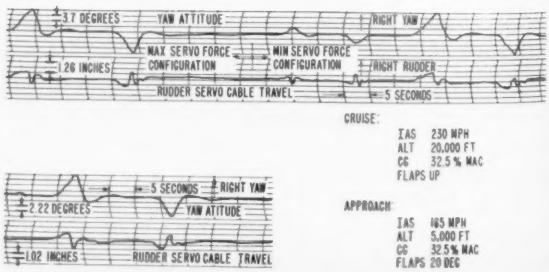
ALTITUDE CONTROL PERFORMANCE SHOWING
RECOVERY FROM LARGE DISTURBANCE

FIG. 6.



PITCH AXIS PERFORMANCE IN DC-7
RESPONSE TO PITCH COMMANDS

FIG. 5



EFFECT OF OVERPOWERING RUDDER

FIG. 7.

automatic pilot on the fleet of 25 DC-7's. The cost of amortizing and maintaining the automatic pilots is $188,800. The net saving is $61,200 per year.

The flights used in this comparison have in them all the elements that go into the actual operation of the fleet. The net result, although derived from fewer comparable flights than is desirable, should weigh heavily with the practical operator who thus far has been unable to obtain data on the automatic pilot saving in cruise flight.

Performance

The automatic flight control system in the DC-7 is the A-12 Gyropilot®. This installation is probably the most up to date in the industry. Behind this extremely successful system is a story of difficult problems encountered and worked out in preceding airplane types. In the case of the DC-7, a cooperative study—in which the airplane manufacturer, the air-line operators, and the equipment manufacturer participated—did much to account for the success of the installation.

The automatic flight control performance that has been obtained in this installation is shown in the following series of recordings. Most of these data were obtained during acceptance tests, but the heading records in Figs. 11, 12, and 13 were made during regularly scheduled flights. Fig. 4 shows the short-period response in pitch for both the cruise and approach configurations. This type of measurement is made by manually overpowering the elevator and then abruptly releasing it. The return to level attitude is both rapid and well damped. In the approach configuration the damping is slightly less than during cruise but still satisfactory.

The response of the system to command changes in pitch is shown in Fig. 5. Here the attitude assumed by the airplane is compared to the signal that is commanding the change. Fig. 6 is a recording of the altitude control operation, showing the ability of the system to hold altitude and also its response to a disturbance. Again, the disturbance is created by overpowering the elevator until sufficient altitude error is built up, then releasing it. Lateral axis performance of similar nature is shown in Figs. 7 and 8.

Some very interesting results of flight tests of the new radio beam coupler are shown in Figs. 9 and 10. The radio beam coupler is replacing the automatic approach control since it provides more accurate path following with a greater margin of stability. To indicate the path accuracy and stability which have been obtained, the beams were displaced and then returned to their original position. Both the beam position and the path of the airplane are shown. Displacement of the beams was simulated, of course, by switching in an equivalent signal.

Fig. 11 is a recording of heading maintained by the automatic flight control system. It also shows heading maintained by the pilot immediately after the automatic pilot was disconnected. Figs. 12 and 13 show heading changes during both manual and automatic approaches. The relative smoothness of the automatic approach is apparent.

New Requirements

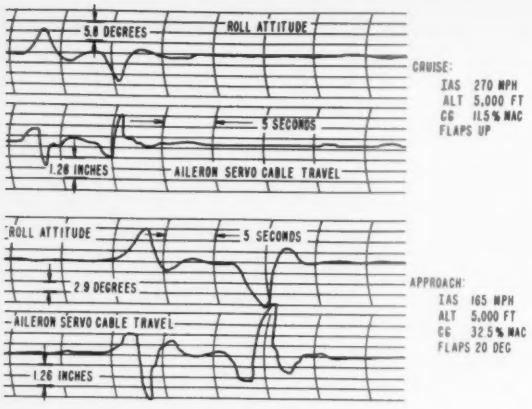
While the performance of the automatic flight control system in present-day aircraft is quite satisfactory, the air-line operator is now concerned with planning for the time when his routes will be traveled by high-speed, turbine-powered aircraft. He foresees a whole new series of these aircraft that will have a significant increase in speed and also new and more critical flight characteristics. A great deal of thought and planning is being directed toward the new operational practices that will inevitably come about. We have had experience with military aircraft, forerunners of our commercial designs, and we are aware of the British experience with the Comet. There is, indeed, a belief that the importance of automatic flight control will increase and that the element of choice with respect to the use of this equipment will disappear. To realize the full benefit of automatic flight control, however, the new requirements that high-speed transportation will involve must be recognized, and equipment must be developed to meet these needs.

The characteristics of high-speed, turbine-powered aircraft as they may affect new automatic flight control systems may be classified as those having to do with (1) aircraft design and (2) operational procedures.

Effect of Aircraft Design

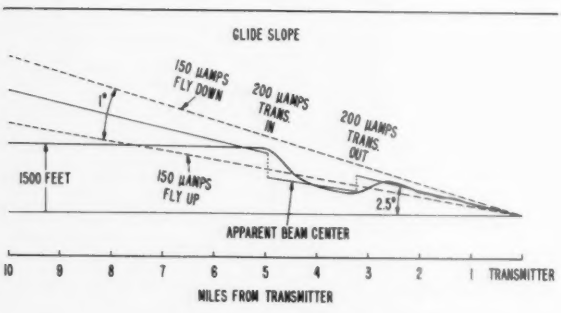
From the point of view of aircraft design, the increased speed and the spread between maximum and minimum speed are major factors. The influence of increased speed is felt directly as it affects the control of flight path and indirectly because of those aerodynamic design characteristics that make high speed possible. While turbine-powered aircraft will fly at high true speeds, indicated speeds will be low during normal high-altitude cruise. Control surface effectiveness will vary through a wide range, and the automatic flight control system will have to account for this by some automatic means.

Because of high true air speeds, a change in pitch attitude will have a proportionately greater effect on rate of climb or descent. The need for precise response to commands for small pitch changes will be correspondingly greater. This may be a requirement in itself to provide accurate pitch control, or it may be required for control to other references such as air speed. In the case of the turbojet aircraft, both the thrust characteristics of the engine, especially at approach speeds, and the aerodynamic cleanness of the airplane without drag brakes contribute to a longer time for the aircraft to respond to power changes. This affects the ability of the aircraft to make the transition from climb to cruise, from cruise to descent, and from cruise speeds to turbulent air speeds and also influences its ability to maintain constant speed during approach.



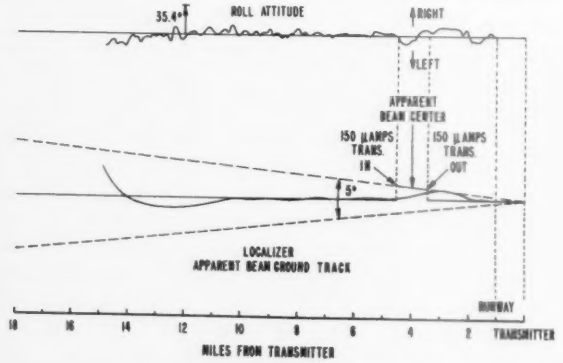
ROLL RECOVERY

FIG. 8.



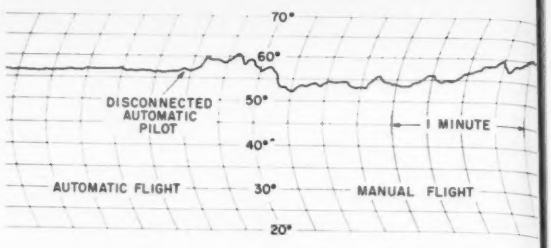
RADIO BEAM COUPLER
GLIDE SLOPE PERFORMANCE-RESPONSE
TO BEAM TRANSIENT

FIG. 9.



RADIO BEAM COUPLER
LOCALIZER PERFORMANCE-RESPONSE
TO BEAM TRANSIENT

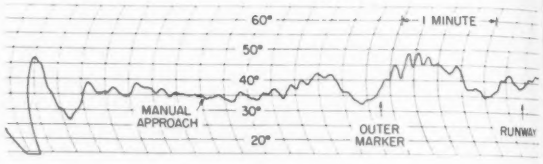
FIG. 10.



DC-7 INSTALLATION
AIRSPEED - IAS 265 MPH
ALTITUDE - 20,000 FEET

MANUAL AND AUTOMATIC PILOT HEADING CONTROL

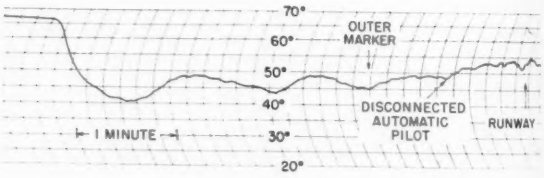
FIG. 11.



DC-7 INSTALLATION
NEW YORK INTERNATIONAL AIRPORT
RUNWAY HEADING 42°

HEADING VARIATIONS DURING MANUAL APPROACH

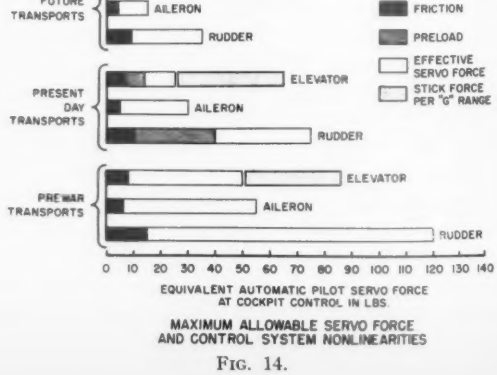
FIG. 12.



DC-7 INSTALLATION
NEW YORK INTERNATIONAL AIRPORT
RUNWAY HEADING 42°

HEADING VARIATIONS DURING AUTOMATIC APPROACH

FIG. 13.



MAXIMUM ALLOWABLE SERVO FORCE
AND CONTROL SYSTEM NONLINEARITIES

FIG. 14.

The high-speed aircraft may be expected to have considerably longer phugoid periods. The phugoid period increases roughly in proportion to the true air speed, and periods of the order of 2 min. and greater can be expected. The longer phugoid periods will place more severe requirements on gyro references and on servo positioning accuracy.

Where swept-wing designs are used, the damping in the lateral axis will probably be insufficient unless a special damping means is provided. The familiar dutch-roll oscillation associated with swept-wing designs will require additional emphasis on precise positioning of the rudder and also upon the minimum deadspot that can be tolerated. Small control surface motions become important in the aileron axis as well, since precise control in roll for small motions of the airplane is necessary in order to help damp out the dutch-roll characteristic.

From this discussion it is apparent that the design of the flight control system may be quite critical from both the manual and automatic control standpoint. In general, the effects of nonlinearities will tend to introduce objectionable aircraft motions in the small amplitude range. Somewhat different characteristics may be expected, depending upon whether control is obtained entirely through aerodynamic means or whether hydraulic boost systems are used. In either case, it is desirable that a system be devised which permits manual control characteristics of the desired type and yet allows completely independent control for automatic operation.

Effect of Operational Procedures

On long-distance flights the heading accuracy maintained by the automatic control system will affect the time of flight in much the same manner as in present aircraft. The importance of aircraft trim will be greater because slight out-of-trim conditions will have a greater effect on drag. Again, the need is emphasized for accurate stabilization of the airplane for small motions and over long periods of time.

In turbine-powered aircraft the procedures used for cruising to obtain the most economical flight will differ greatly from presently operated aircraft. In aircraft powered with reciprocating engines cruising flight takes place at constant power and constant altitude. In turbine-powered aircraft both air-frame and engine characteristics determine the conditions for best cruising operation. With certain cruise flight procedures, the altitude increases slowly throughout the cruising portion of the flight. While the conditions for maximum cruising economy can be defined and simplified procedures can be worked out, it is not yet determined to what extent such procedures can be used from the traffic-control viewpoint.

Many of the very short air-line routes are not profitable today and may even represent a loss to the air-line operator. Services on these routes are naturally kept to a minimum, and some air lines do not use automatic flight control in these operations. It is expected, however, that increases in population density and greater acceptance of air transportation by the public will chanpe the present economics of route structures. On the larger transport systems in particular, increased nonstop service directly between large population centers will be provided, and this will influence the type of transport which is developed. The replacement for present twin-engined short-range transport aircraft will probably carry 55–65 passengers at an average speed of 325–350 miles per hour. It will undoubtedly be turboprop powered. It is expected that the use of automatic flight control in short-range transport operations will increase greatly, and this will influence the development of new systems.

The expected increase in short-range operations will require more emphasis on the climb and descent portions of the flight. The climb and descent phases become more important, too, because, with higher cruising altitudes, they consume a greater proportion of the total flight time. The approach and landing phase will receive greater emphasis when automatic flight control is in widespread use for short-range operations, as will the transition from descent to approach and from approach to visual contact.

Specific Requirements

Specific requirements that new automatic flight control systems will have to meet may be classified in this manner:

(1) Improved accuracy of components and subsystems.
(2) Improved airplane flight control characteristics.
(3) New flight functions to be performed.
(4) New and simpler procedures for the pilot.
(5) Minimum complexity and increased reliability.

The accuracy of the servo system should be stressed. The servos should have the ability to move the control surfaces through extremely small angles even though relatively high breakaway forces exist. Furthermore, the response of the servo system at small amplitudes should contribute a minimum of phase lag so that the automatic flight control system will be able to damp out any tendency toward small amplitude oscillation. Certain parameters in the automatic flight control system which are critical to speed or other changes in configuration will be varied automatically to hold approximately constant sensitivity. Maximum servo force may also have to be varied automatically to ensure safety and at the same time allow good performance throughout the entire range of operation. Fig. 14 is a chart relating maximum allowable servo force to control system nonlinearities for different series of aircraft. The range of force to produce one maneuvering g is also shown. The chart highlights the importance of the ratio of maximum servo force to friction and preload.

The accuracy of the vertical gyro should be such that it is unaffected by either fore and aft or lateral accelerations. This means that the erection sensitivity should be sufficiently low that negligible precession of the gyro takes place during periods of long, slow ac-

celeration and deceleration. The time constant of the erection system should be at least equal to, and preferably greater than, the phugoid period of the airplane in seconds per radian. The vertical reference may also be compensated for accelerations—that is, accelerations may be measured and compensating torques applied to the gyro. The directional reference should be suitable both for coupling to a magnetic reference and for use as a free gyro in high latitudes. When the directional gyro is monitored by a magnetic element, the coupling must be extremely loose so that the system will be stable on North headings. Both the characteristics of the directional system and the sensitivity of the vertical gyro to lateral accelerations affect the stability of the system on North headings.

The automatic flight control system will be required to perform new flight functions during climb and cruise. For climb and descent the control of pitch attitude alone may be insufficient, and more direct references such as rate of climb or air speed may be used. Either of these types of control will give the pilot a means of climbing or descending more appropriate to his needs. During the cruise portion of the flight, a different mode of control may be required. The reference for this mode may be a simplified computer that will determine the approximate conditions for maximum economy and control the pitch attitude accordingly.

Pilot flight procedures will change considerably in high-speed airplanes. A determined effort is needed to relate more intimately the procedures used in manual flight to those used during automatic control. One area where this may be fruitful is in the method of commanding maneuvers, turns, and pitch changes. Considerable progress along this line was made when the control knobs for maneuvering were grouped together and their motions related to the desired motions of the aircraft. The next step should require from the pilot no more than one method of commanding maneuvers, whether he is flying the airplane manually or under automatic control. From the pilot's point of view, the transition from manual flight to automatic and from automatic to manual is a region requiring improvement. The pilot should not be required to level the wings accurately nor to trim the airplane with care when turning on the automatic flight control system. Procedures for entering the approach phase after the descent from altitude should be simple. During an automatic approach, continuous monitoring of the operation by another flight reference is required. In the event the pilot decides to discontinue an automatic approach but to continue the approach manually, an indicating system that has been continuously in operation must be immediately available for his use. Transition from automatic approach to visual contact and manual landing must require no special procedures.

Because of additional requirements on accuracy and because more flight functions will be performed automatically in high-speed aircraft, it is almost inevitable that the complexity of the system will increase. Along with increased complexity, there is danger of less reliability when in fact more reliability is needed. There are two approaches to the solution of this problem, and both will have to be pursued. The first approach deals with components and the use of more recently developed elements. These must be utilized in a manner that will provide reliability in early installations. In other words, design must be conservative. The use of components or combinations of elements that are identical but are used repeatedly to build up more complex units can increase reliability, since a greater degree of refinement of the elements is possible, and because routine maintenance is made easier.

The other approach to countering the result of increased complexity is the integrated system idea. This is much more sweeping in concept, and if applied in a broad sense can actually reduce overall complexity. In this case the integrated system concept involves the design of a broader system than the automatic flight control. A group of related systems are designed together with the common requirement of satisfying the special needs of high-speed transportation. Integration starts at the cockpit, with the control column and with the pedestal controller of the automatic pilot, so that the automatic pilot is controlled through the manual control system. Integration continues at the control surfaces, with the automatic pilot servo and power control or aerodynamic boost, with semiautomatic controls, dampers, and the like. Finally, the automatic pilot instrumentation is integrated with the instrument display to the pilot and with the flight director. Overall complexity can be reduced with this kind of design since references and servos can be common to several functions—for example, power control, damper servo, and automatic pilot servo can be combined into one. Also gyro instruments can be used for multiple purposes as is done in the new Integrated Instrument System. Reliability can be increased because an overall design can more easily provide for degeneration of the complete system into lesser but still operable systems.

Conclusions

An analysis has been made of coast-to-coast DC-7 nonstop operations to determine the possible saving through the use of automatic flight control. A saving in flight time of approximately $1\frac{1}{4}$ per cent is indicated. This figure may be low, and further study is recommended to verify the results.

The performance of the automatic flight control system in the DC-7 is shown as representative of satisfactory present-day installations. This performance may be used as a basis for establishing automatic flight control requirements for new high-speed transport. Discussion of the characteristics of high-speed, turbine-powered aircraft and the probable operational practices that will result brings out that the automatic flight control system will have to meet many new requirements. Among these are increased accuracy, new modes of control, and simplified pilot procedures. The tendency toward increased complexity which these new requirements encourage must also be met.

A Wider Choice of Missile Control Instrument Functional Characteristics

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A GUIDED-MISSILE control system designer is forced to work with a limited freedom of choice of characteristics in the instruments needed for missile control. For example, the relationship between instrument natural frequency and range usually requires a compromise. Electrical filtering of the instrument output may be required to restrict the information to the passband used in the control system. Or, the instrument may have to be used over a range for which it was not designed.

Work at Boeing has, for the last year, been directed toward providing missile control instruments in which the functional characteristics can be specified independently of one another. A rate gyro with this property has been completed and tested and will be described in some detail. However, it is believed that it is possible to go further, using the techniques employed in this rate gyro, and build an instrument that performs the necessary functions to replace several conventional instruments plus their associated electrical circuitry.

Consider first the rate gyro. The conventional rate gyro is a strong example of an instrument in which the functional characteristics are interrelated. The form of this interrelationship of characteristics is given in the expression

$$\omega_n = \sqrt{\frac{H\Omega}{I_g\theta}}$$

where

ω_n = natural frequency
H = angular momentum of the wheel
Ω = applied rate about the sensitive axis
I_g = moment of inertia of the gimbal about the output axis
θ = gimbal angular deflection at Ω

Recognizing that I_g/H represents the sensitivity of the gyro to angular acceleration about the output axis and that sin θ represents the sensitivity to rate about an axis perpendicular to the input and output axes, the equation for natural frequency can be considered to interrelate all the functional characteristics of the conventional gyro.

However, this interrelation of functional characteristics can be avoided. First, the angular acceleration cross coupling can be eliminated altogether by adding a moment of inertia constrained to move in opposition to gimbal precession. Second, the natural frequency can be independently controlled by providing the correct gear ratio between this added moment of inertia and the gimbal. Rate cross coupling can be made arbitrarily small by stiffening the gimbal restoring spring.

Fig. 1 shows how the rate gyro parameters must be selected in order to eliminate angular acceleration cross coupling and independently control natural frequency. Proper selection of the gear ratio and the added moment of inertia allow both elimination of angular acceleration cross coupling and choice of natural frequency because the first power of the gear ratio determines the acceleration sensitivity, while the square of the gear ratio determines the natural frequency. And, last, the gyro output can be made independent of gimbal travel and hence of rate cross coupling by driving the transducer with a multiplying linkage.

Whether or not it is practical to employ these simple principles depends on the form that their mechanization takes. The gyro presented here is not complex. It uses an oil mass as the added moment of inertia. Positive displacement vanes connect the oil mass to the gimbal. Proper routing of the oil path provides the restraint for the oil to move in opposition to gimbal precession, and proper shaping of the oil passage relative to the gimbal vanes mechanizes the gear ratio.

The moving element of the transducer is located in the oil path so that the linkage ratio between the gimbal and the transducer is mechanized by the ratio of the gimbal vane area to the transducer cross-section area.

Fig. 2 shows the schematic drawing of the rate gyro with its reverse oil path. The gimbal axis is perpendic-

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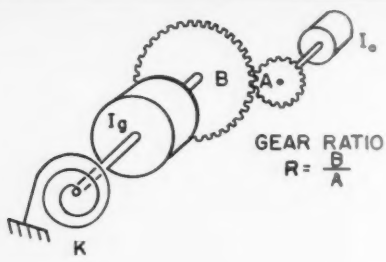

1) SYSTEM IS INSENSITIVE TO ANGULAR ACCELERATION WHEN

$$I_o = \frac{I_g}{R}$$

2) SATISFYING 1) THE NATURAL FREQUENCY IS

$$\omega = \sqrt{\frac{K}{(1+R)I_g}}$$

FIG. 1. Control of angular acceleration cross coupling and natural frequency.

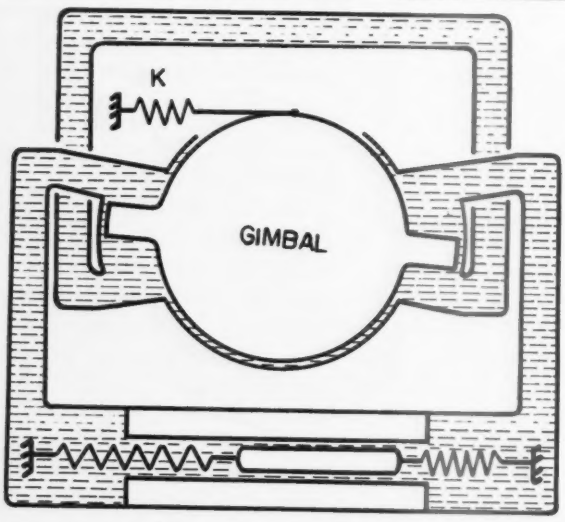

FIG. 2. Rate gyro schematic.

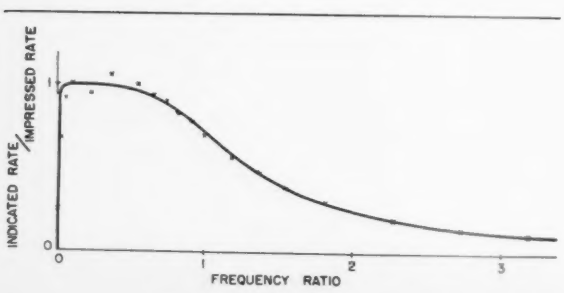

FIG. 3. Rate gyro response

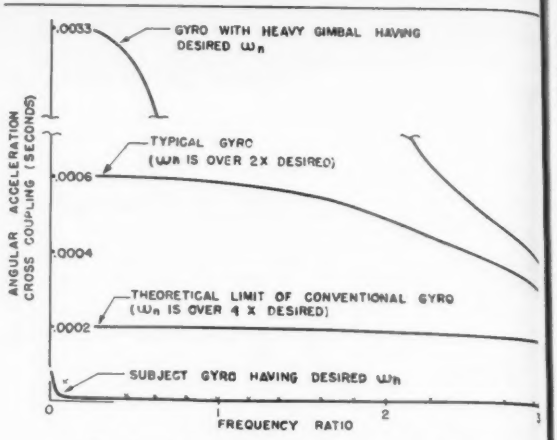

FIG. 4. Angular acceleration cross coupling.

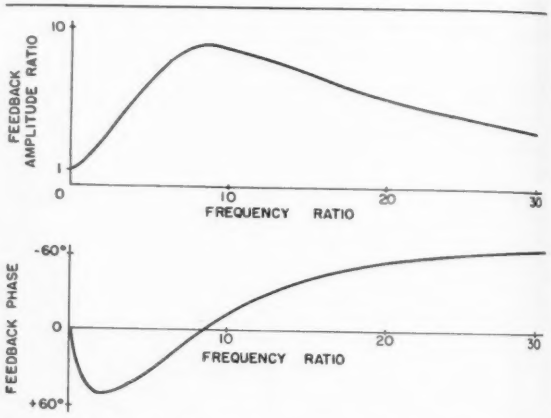

FIG. 5. Angular feedback requirements for a missile control system.

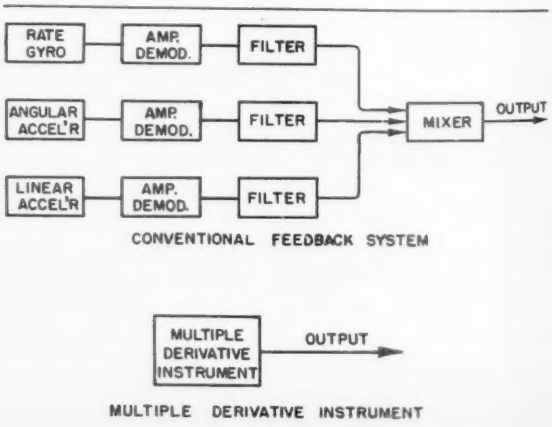

FIG. 6.

ular to the plane of the paper. Note that two vanes are used, one at either side of the gimbal. The upper half of the oil circuit originates at the lower face of one vane, passes over the top of the gimbal, and terminates at the lower face of the other vane. The lower half of the circuit is a mirror image of the top, except that the transducer element is located in the bottom of the oil path. Precession of the gimbal, for example, in the direction shown causes oil to move in the oil path, displacing the transducer as indicated.

The effective radius from the gimbal axis to the oil path and the effective cross section of that path determine the oil moment of inertia. The ratio of vane area to effective oil path cross-section area determines the gear ratio.

Note that the coupling between the gimbal and the transducer moving element is not rigid. A controlled amount of oil leakage past the transducer is provided. The transducer element is neutrally floated in the oil and lightly spring restrained to its zero output position. This method of coupling the transducer element to the gimbal removes the steady-state errors associated with bearing friction, gimbal unbalance, and gimbal spring hysteresis. The effect on the rate gyro output is to discard steady-state rate information. With dynamic rate applied to the rate gyro, its output rises approximately linearly with frequency in the fashion of a first-order system. The break frequency of this first-order property can be controlled independently of all other characteristics by selection of the oil leakage past the transducer element or selection of the centering spring stiffness. By choosing a sufficiently low break frequency, the missile dynamics are not affected.

The resulting overall frequency response of this rate gyro is characterized by a rapid first-order rise, followed by a conventional second-order drop. Fig. 3 is a plot of the calculated response. The points are test data. There is some discrepancy in the slope at the left side of the curve caused by an error in the stiffness of the transducer element restoring springs. However, on the linear scale presented here the agreement between calculated and test data is good.

Fig. 4 is a plot of the calculated angular acceleration cross coupling vs. frequency for the subject rate gyro and for three conventional rate gyros having the same gimbal deflection as the subject gyro. Again, the points are test data on the subject rate gyro. The top curve is the angular acceleration cross coupling of a conventional rate gyro having the same natural frequency as the subject rate gyro. Note that the vertical scale is broken. Here the desired frequency response is obtained at the expense of a prohibitive amount of angular acceleration cross coupling. The next curve down represents a fairly common rate gyro design—i.e., 0.0006 sec. time constant. Its natural frequency is over twice the desired value. The curve below that represents the theoretical limit of a conventional rate gyro with a 24,000-r.p.m. wheel. Its natural frequency is nearly four times the desired value, making additional filtering absolutely necessary. Nevertheless, its angular acceleration cross coupling is substantially worse than the subject rate gyro.

The tests on this rate gyro have satisfied us that it is practical to build instruments with a wide choice of functional characteristics. Turning again to the general problem of controlling a guided missile, we have looked to see what instrument characteristics are needed. In the general case, the missile's aerodynamics, its structural dynamics, and the control equation chosen combine to place a requirement on the phase and amplitude response of the feedback information. Fig. 5 is the typical form of such a curve for missile angular motion. The frequency scale is normalized for the missile weathercock frequency. The total feedback information is composed of that curve plus properly shaped linear acceleration feedback.

The missile designer ordinarily satisfies these curves by employing a number of conventional feedback instruments to sense the missile kinematics. Each of these instruments requires electrical filtering so that it will exclude information in the frequency range not used in the control system. The filtered instrument outputs are then electrically mixed for use in control of the missile. Fig. 6 is a block diagram of this usual method of satisfying the feedback requirement. In addition, it shows our design goal of providing a single instrument that inherently combines the missile motion derivatives in a fashion that satisfies the feedback requirements.

The mechanism of this instrument is much the same as that of the rate gyro. The basic principle is to bring hydraulic pressure to bear on a spring-loaded transducer element. This pressure must be the sum of a number of pressures each of which is proportional to a missile motion derivative. In addition, the pressure associated with each derivative must have the proper

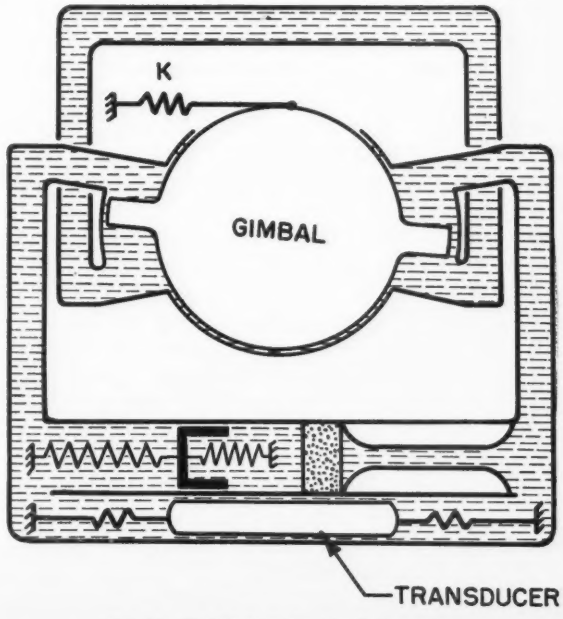

FIG. 7. Multiple derivative instrument.

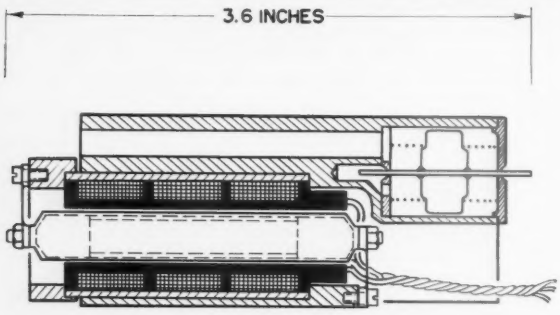

FIG. 8. Multiple derivative capsule.

frequency response. Fig. 7 is the schematic drawing of this multiple derivative instrument. Note that oil moving in the lower passage has two parallel paths. One is to move the transducer element against the stiff restraint of its restoring spring, the other is to pass through a series of elements in a by-pass around the transducer. The by-pass handles most of the flow so that pressure drops can be developed in it proportional to missile motion derivatives. The oil is driven by a rate gyro so that oil position is proportional to missile angular rate. A pressure drop proportional to oil position is developed across the spring-loaded plug in the by-pass. The next derivative of missile motion—angular acceleration—produces oil velocity. A pressure drop proportional to oil velocity is developed across the porous plug in the by-pass. The next derivative of missile angular motion—angular jerk—although not commonly used, is helpful in shaping the feedback curve. It produces oil acceleration. A proportional pressure drop is developed across the Venturi in the by-pass. These series pressure drops bear on the transducer element, deflecting it proportionally against its spring. Linear acceleration is sensed by having the transducer element denser than the oil. The proper frequency response for the linear acceleration information is obtained by shaping the Venturi in the by-pass so that it will present the correct amount of effective oil mass to the transducer element.

Fig. 8 shows a design drawing of a capsule that can be inserted into the oil path of the existing rate gyro to convert it to the multiple derivative instrument. Details of the design appear practical for an instrument having the characteristics required to control a high-performance guided missile.

In summary, it can be said that a rate gyro has been built in which the functional characteristics have been specified independently of one another. The gyro has been shown to perform as designed. Such instruments could be used in missile control systems with increased missile reliability and decreased complexity.

Using the techniques demonstrated in the rate gyro, an instrument is proposed that performs the functions of a group of missile control instruments plus associated electronic circuitry. Use of such an instrument offers the possibility of greatly increased missile simplicity and reliability.

Electronics in Aviation (*Continued from page 58*)

system to reach the target, the chances are good that it can still be told that New York City is in Alabama or off Montauk Point. We cannot forget, either, that the enemy knows this to be true and is engaged in countering our measures. This is a large field that needs a lot of attention. I have thought, on occasion, that it should be specified in the design of a new electronic system for aircraft that the designer must also produce at the same time a study of how his system may be countered. Certainly a designer who has paid little attention to the antijamming qualities of his system has done less than his full duty.

In summary, then, electronics and aviation have gone a long way together but there is still a longer way to go. The electronic designer must direct his efforts toward simplifying his equipment and reducing its weight and unreliability. Equipment delivered to the operating forces must be fully developed and ready to operate and must be engineered for the purpose at hand. The designer must avoid overengineering the problem or wasting his efforts in the achievement of minor or unrewarding goals. The airplane designer must avoid the pitfall of using electronics solely for the sake of using electronics or of attempting to compete in electronic design with the man whose experience and capabilities cannot but make him superior. Together they must cooperate to the fullest in the joint design of airplane and electronic gear to assure maximum returns from both.

Finally, I firmly believe in feet-on-the-desk research and the setting of the development goal before starting the development. Perhaps some of you remember the story of the boy and his grandfather who stepped out of the back door of the farmhouse just after a new fall of snow had left a glistening blanket on the fields. Looking across the field to a tree on the other side, the boy said, "Grandfather, let's see who can walk the straightest toward that tree." Despite watching his feet very carefully to be sure he placed each one directly ahead of the other, when they reached the tree and looked back, the boy saw that his tracks wandered quite a bit, whereas his grandfather's were straight as a string. "How did you do that, Grandfather," asked the boy. "That was easy, Son, I just watched the tree." Our tree is simply the winning of the war against any possible enemy. Let's keep our eyes on it.

A Compass-Controlled Directional Gyro System for Today's Fighter Aircraft

HAROLD E. TREKELL* AND HAROLD S. WHITEHEAD†

General Electric Company

FOR YEARS MAN FLEW AIRCRAFT by the seat of his pants and a magnetic compass. World War II brought the remote magnetic compass and the directional gyroscope into almost universal use. The former was one step better than the magnetic compass since the primary detector could be located remote from the cockpit in a "magnetically clean" location in the plane. But acceleration and turn errors were still present.

The directional gyroscope overcame these problems and introduced a new one—drift. By periodically setting the gyroscope to the compass heading during straight and level flight a great gain in compass navigation accuracy was obtained.

Pilots were not setting their gyros to compass headings for long when it was realized that such an operation could be better performed automatically. Thus was born the compass-controlled directional gyro system.[1] In this system (see Fig. 1) a remote compass transmitter is the primary detector of direction. By comparing the position of the compass to that of the gyro through a suitable pickoff on the gyro an error voltage is produced which is phase sensitive to the difference in positions. This voltage is amplified to obtain sufficient power to precess the gyro by a torque motor until the gyro is synchronized to the compass transmitter. By continually correcting the gyro at a slow rate drift errors are eliminated, while its momentum prevents the gyro from following the "wobbling" of the compass. Thus the pilot has a suitable drift-free indication of heading.

Lately a new requirement has become of prime importance—namely, a low free-gyro drift rate. When compass-slaved operation is satisfactory, a relatively high drift is acceptable from the gyro as long as the compass transmitter is sufficiently accurate to correct it. Today's flying requires compass information at times when the compass transmitter is not sufficiently accurate. Such conditions exist during polar flights and occasionally during GCA landings. In the former case the horizontal component of the earth's magnetic field is insufficient to detect accurately. In the latter, local magnetic disturbances can cause gyro precession resulting in deviation from a straight flight path. Under such conditions it is necessary to use the gyro alone as the heading reference, and the requirement for a low drift characteristic becomes obvious.

The G-2 Compass is now becoming obsolete, not from principle but because today's fighter aircraft require even better accuracy; and with standardization on omnirange's radio magnetic indicator there is no place in a crowded instrument panel for the gyro element.

With this introduction we will now discuss the Navy type MA-1 Compass System developed by the General Electric Company to meet the Bureau of Aeronautics specifications for a system to succeed the G-2 System.

After considerable development and specification review, the MA-1 Compass System was starting to take shape by mid-1951. One of the first requirements, and probably the only one that was never changed, was a 4° per hour maximum drift rate when operated as a free gyro—that is, without the compass-slaving feature in use. This was further expanded to include a 4° per hour maximum drift rate any place in the world which required some means to compensate for the apparent drift of the gyro due to the earth's rotation, or as it is now commonly known, "Latitude Control." During extensive successful flight tests of a development sample unit, it was possible to evaluate system features under operating conditions and determine what requirements were necessary for further production design.

The new specification requires a 4° per hour maximum system drift limit at any latitude under any variation of voltage, frequency, or temperature normally encountered in flight. This drift is the actual drift compared to a perfect system and not random drift, which is essentially the difference between peak and average drift in a given run. In addition to the requirement of operating as a free-gyro system, provision is, of

Presented at the Instrument Systems and Simplification Session, Twenty-Third Annual Meeting, IAS, New York, January 24-27, 1955.

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† Supervisor—Gyro Navigational Instrument Engineering, Instrument Department.

FIG. 1. Navy Type G-2 Compass System (*left to right:* remote compass transmitter, gyro master direction indicator, and amplifier).

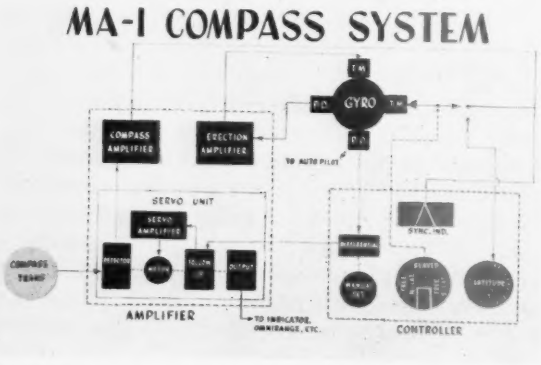

FIG. 2. Block diagram of Navy Type MA-1 Compass System.

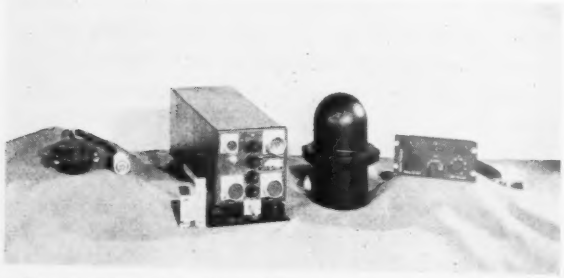

FIG. 3. Navy Type MA-1 Compass System (*left to right:* remote compass transmitter, amplifier and servo, remote gyro and controller).

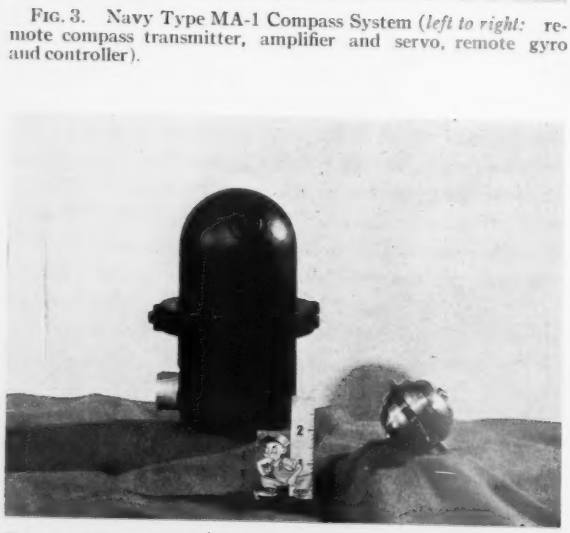

FIG. 4. Remote gyro unit with gyro element showing symmetrical motor design of high momentum-to-weight ratio.

FIG. 5. Cutaway view of remote gyro.

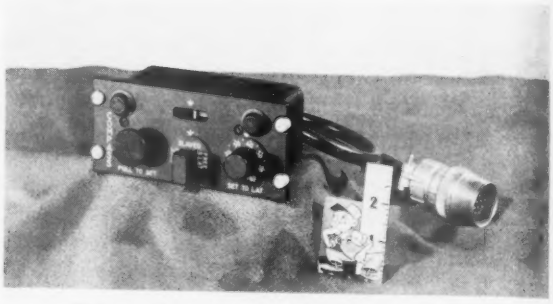

FIG. 6. Controller for MA-1 Compass System.

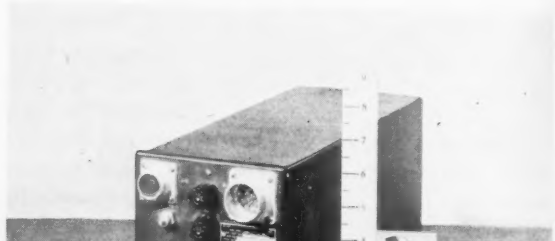

FIG. 7. Amplifier and servo unit for MA-1 Compass System.

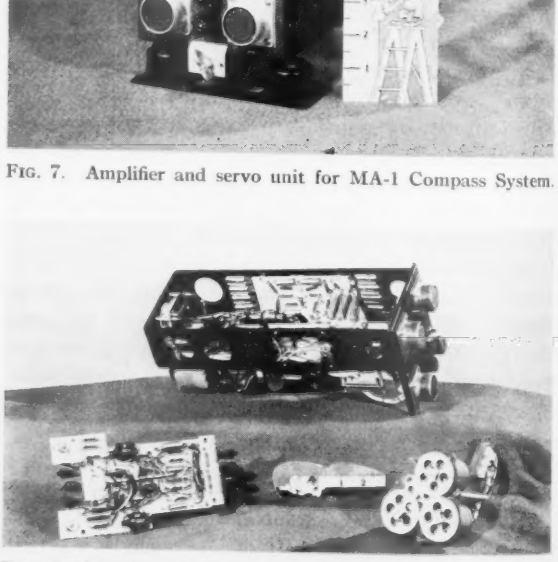

FIG. 8. Amplifier and servo unit for MA-1 Compass System showing "plug-in" components removed for simplified servicing.

course, made to operate the system with the gyro element slaved to the compass transmitter. This latter mode of operation is normally used except for polar flight or unusual conditions such as GCA landings as mentioned before.

To meet the basic requirements of a 4° per hour free-gyro drift rate two possible approaches were considered. The first was to make the gyro big enough to swamp out any loads connected to it. The second was to isolate any load torques from the gyro. The latter method was chosen since the designer has no control over the load that might be coupled to the system. The ARN-14 or ARN-21 omnirange system that is frequently used with the MA-1 Compass presents a serious load requirement particularly during low temperature operation. This isolation feature adds complexity although the overall system weight is not greatly affected since a small accurate gyro can be used. Further, the drift accuracy of the gyro can be depended upon since there are no variable reflected load torques.

The block diagram (see Fig. 2) shows the functional operation of the gyro compass system. First consider the operation of the system as a compass-slaved directional gyro.

A synchro transmitter pickoff on the gyro feeds through a differential synchro, operated by the manual set knob, to the follow-up control transformer on the servo unit. If the synchro transmitter and control transmitter are not synchronized (as modified by the manual set differential synchro) an error signal is developed by the follow-up synchro control transformer, amplified and used to drive the follow-up synchro to synchronization. Geared to the control transformer are the detector and output synchros.

If the detector synchro and the compass transmitter are not synchronized, an error signal is generated by the detector synchro, amplified and used to precess the gyro, which is followed by the servo, until synchronization occurs. For quickly setting the heading the pilot turns the manual set differential synchro until the detector is synchronized with the compass transmitter as indicated by the synchronizing indicator. A leveling pickoff on the gyro produces a phase-sensitive signal that, when amplified, is used to erect the gyro to a level position.

During free-gyro operation the amplified compass error signal is removed from the gyro precessing torque motor, and a suitable current provided by the latitude control is applied to precess the gyro at the proper rate to offset the effect of the earth's rotation. By means of the manual set knob, the desired heading can be quickly set.

It is recommended that navigational equipment, including repeater synchros, be operated from the servoed output synchro, while the autopilot, when required, be operated directly from the gyro output synchro. This permits changing the heading setting at will without affecting the autopilot. Should it be desirable to operate an autopilot from the servoed output, a switch is included in the controller to disable automatically the autopilot if the heading is changed. This prevents any violent maneuver should the pilot accidentally change the system heading while the autopilot is engaged.

The General Electric version of the MA-1 Compass is packaged in four units (see Fig. 3). The compass transmitter shown is a new development now being placed in production. It is of the earth inductor type containing no moving parts except that the element is pendulously supported. Improvements over previously available transmitters include:

(1) No effect from accidental exposure to permanent magnetic fields.
(2) 125°C. ambient temperature operation.
(3) Hermetic sealing.
(4) Small size for thin wing aircraft or tail mounting.

The gyro unit (see Fig. 4) is a remotely mounted unit and hermetically sealed. The heart of the gyro is a new motor of completely symmetrical design with a high angular momentum to weight ratio. This characteristic is obtained by dispensing with the conventional motor frame or gimbal and the use of titanium rotors supporting tungsten alloy rims, thus placing the major weight of the rotating elements at the greatest radius. The overall result is a motor of minimum static weight and maximum angular momentum, or, minimum friction with maximum torque. Objectionable torques such as windage, spiral, mass shift, and bearing friction have been kept to a minimum throughout the design.

Two coils mounted on the main gimbal (see Fig. 5) intercept the leakage flux of the motor, producing a signal that is phase and amplitude sensitive to the position of the rotor with respect to the main gimbal, which is used as the leveling reference. The leveling torque motor is of the hysteresis type, while the precession torque motor operates on direct current thus preventing any accidental coupling effects.

A small window in the case of the gyro permits observation of its performance, and a calibrated dial is provided on the major axis for test purposes and as a convenience for calibration. An internal brake is provided to prevent any possible nutation while coming up to speed or spinning when power is removed. The case must be mounted vertically but the angular position is immaterial to the operation of the System. The overall dimensions of the gyro are $7^3/_4$ in. high by $6^1/_4$ in. in diameter. The weight is $5^1/_4$ lbs.

The controller unit shown in Fig. 6 contains all the controls for the operation of the System and is mounted in the cockpit. The left-hand knob (which returns to neutral automatically to prevent accidental setting) is used to set the system to the desired heading. Under compass-slaved operation the synchronizing indicator (center top) permits the operator to do this without reference to other indicators. The synchronizing indicator continues to monitor the system heading with the compass heading as a check on the operation of the slaving circuits. A red flag in the synchronizing window disappears from view when power is applied to the sys-

(*Continued on page 119*)

Effects of the Systems Approach on Reconnaissance Equipment Design

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THE SYSTEMS APPROACH has affected many fields within the past few years. Aerial photographic reconnaissance and aerial survey have been no exceptions. Perhaps it has been even more strongly evident in this field than in many others. The effects of this approach are broad, influencing not only the design and manufacture of aerial photographic systems but also contractual and economic relations—and even end performance capabilities and requirements as well. In the design of aerial photographic systems, this approach has done a great deal, within a relatively short length of time, to accelerate significantly the advancement of the art.

When one considers this subject of the Systems Approach, one soon finds it is quite complex. The very word "system" has many meanings. Used with respect to aerial reconnaissance, it still connotes several things. There are both major and minor systems. There are systems within systems. In the broad, overall area, there is the Defense System. Within it, as one of its many functional parts, there is an Intelligence System. Within this category, there are also many parts—one of which is the Aerial Reconnaissance System. Even at this level a system has many facets and encompasses many functions. It comprises, among the more important things, the equipment necessary, the techniques for the operation and use of the equipment, and the organizations and the people who operate it. Each of these is inseparably related to each of the others. Its operation also breaks down into a number of functions including Operations Planning, Data Collection, Data Processing, Interpretation, Presentation, and Distribution. Each of these is also inseparably related to each of the others. Again, within this system, considering one of the parts—such as the Data Collection System—we find that this in turn consists of a number of parts or smaller systems. A typical breakdown would certainly include the aircraft, the photo system, the navigation or guidance system, and the supporting equipments and systems. Finally, the photo system would include several parts such as cameras, mounts, controls, power supplies, and perhaps many more items depending on the particular case.

Systems Design and Systems Development are not new discoveries. The aircraft companies and the military organizations have been doing this for years. Aerial survey and reconnaissance have always involved systems. The first time an aerial camera was put into an aircraft, a system was formed. With the ever-increasing demands for greater performance and more capabilities, these systems have become infinitely more complex.

There are two basic approaches to systems design in photo-reconnaissance—namely, a component approach and the systems approach. In the component approach, the system design and capabilities are dependent upon the capabilities and characteristics of the components. It might be said that the system is the dependent variable and the components the independent variables. This has been the traditional approach and is still no doubt the one that most designers and manufacturers feel at home with. In the systems approach, however, the components' characteristics are established by the systems requirements. The system becomes the independent variable and the components the dependent variables. Figs. 1 and 2 illustrate the essential differences between the component and the systems approach, as interpreted here.

Let us first consider the component approach. Fig. 1 represents a block diagram of the steps involved in the system design process under this scheme. There are actually two starting points, and the process involves a certain amount of compromise in order to bridge the gap between them.

One starting point is the availability of components to do most of the jobs desired. In the photo-reconnaissance field, equipment is generally designed and manufactured as components but used as parts of systems. Behind the existence of available components

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is, therefore, consideration of the various applications for the components. This involves some investigations of probable system requirements and analyses to determine the requisite component characteristics. The component manufacturer takes into consideration all the applications he knows of and establishes his specifications to satisfy the largest number of uses he can accommodate. Having established his design, he produces the component and attempts to sell it either as is or with minor modifications to everyone having a use for it.

The other starting point is the end customer with a new system requirement. When the customer has defined his problem, the system designer attempts to visualize how he can put together various available components to form a system that will do the required job. The evolution of his functional outline is somewhat of a juggling process. The functional outline is considerably dependent upon the characteristics and capabilities of the available components. He carefully analyzes these characteristics, the inputs and outputs and the ways the various components work together and effect each other. He may request modifications to existing components. Or he may interpose a new component—an adapter, in effect—between existing components to complete the outline of the system. This obviously influences component specifications and form, and it tends to keep the status of available components up to date with the various applications. Effective system design under this scheme is dependent upon the existence of a large store of diversified components covering a wide variety of functions.

Fig. 2 portrays the systems approach as envisioned in its application to the design of photo-reconnaissance equipment. Here there is a single starting point—the customer with his definition of a job to be performed by a system. The system designer analyzes the requirements of the job and proceeds to outline a system to satisfy the requirements. His next step is to determine the component specifications—their features and performance requirements necessary to fulfill the system requirements. From here, the process proceeds along two paths. One concerns the survey of existing components, their characteristics and performance. The other concerns the design investigations of the possibilities and potentialities of new component designs. After analysis of the system performance obtainable from both these methods and even from combinations of both, the system designer reconsiders his functional outline and evaluates other variations of it which may be indicated by the various component possibilities he has explored. Finally, taking into account a number of different factors, he selects the optimum combination for the make-up of the desired system. Detailed component specifications must then be prepared for all parts of the system. If individual components do not already exist to meet these specifications, they must be designed, manufactured, and tested. In choosing between the use of an existing component and the design of a new one, a careful evaluation must be made of the advantages and penalties in each case. The improvement in system performance resulting from design of new equipment must be weighed against possible complication of the logistics involved. It is essential that all criteria used in reaching a decision be assigned the proper weighting factor.

Under both the component approach and the systems approach, a certain degree of compromise is inevitable. Under the component approach, it usually turns out that the system performance is penalized in one or more ways because of the limitations of available components. As newer and more stringent system performance requirements have been established, it becomes increasingly difficult to develop a satisfactory system in this manner. Under the systems approach, the development of a system to meet advanced performance requirements is facilitated in two ways. First, the system designer is relieved of many restrictions and limitations by being permitted to establish the component requirements to suit the system or end use requirements. Second, by the very nature of the task the designer must evaluate the effect of each component on system performance and determine the extent to which improvement in component performance improves system performance; thus he concentrates on improving the performance of those components where the net effect on the system performance is greatest. This type of evaluation may even require the acceptance of a component of less than theoretical optimum performance if this lesser performance has a negligible effect on system performance, and a net gain, such as decreased weight or power or increased reliability, etc., accrues to the system.

Generally speaking, in the past, most of the development of aerial photographic equipment has been on a component approach basis. It has been stimulated by the basic philosophy that all improvement in component performance would certainly contribute to an improvement in system performance. This has, of course, resulted in a steady year-by-year improvement in the equipment but has generally not produced any radically new or different approaches.

In recent years, however, emphasis has swung around to the systems approach. Primarily this has been necessitated by the increasing complexity of photo-reconnaissance systems as utilized in present-day aircraft. It might be said that this trend was inevitable in view of the rapidly expanding performance capability of newer aircraft types and the inability of the human operators to keep up with the performance of the aircraft. A secondary factor in the adoption of the systems approach is, no doubt, the increasing costs of individual components and part improvement programs as required under the component approach. The state of the art had been reached where, in many instances, further improvement in component performance contributed little to the overall system performance improvement yet was extremely expensive. A need for evaluation of the overall problem and determination of

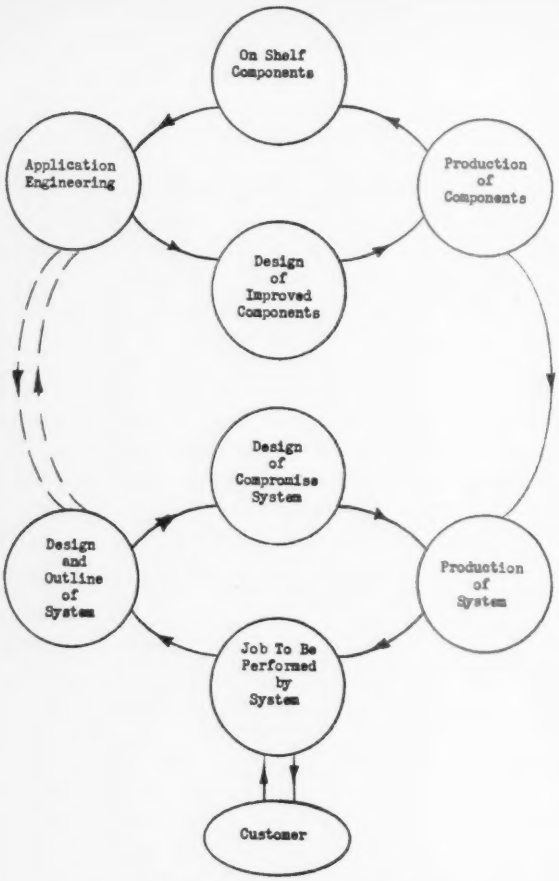

FIG. 1. Component approach.

new approaches and areas where major advances could be made was recognized by the Air Force, Navy, aircraft companies, and certain individuals. Credit for far-sighted pioneering must be given to their leadership that has resulted in this change.

Thus, within the past relatively few years, considerable analysis of the factors affecting overall photo-reconnaissance system performance has been done with a view toward a determination of the most profitable courses of development. Several studies have been made under sponsorship of both the U.S. Air Force and Navy into the basic requirements of the photograph—the kind, form, size, and quantity of detail necessary for the various use purposes and the means and methods of interpreting them. Other studies have simultaneously been made of the manner and extent to which the overall system performance is dependent on and affected by the various parts. Thus it is now possible to outline the optimum performance required for the task and to indicate the places where the effort must be concentrated in order to achieve it. It is also possible to see where present component capabilities are, in some instances, beyond what is required or usable. Savings may therefore be made through the elimination of features and refinements or through employment of simpler or more elementary devices.

Let us now examine a typical air-borne data collection (photographic) system for reconnaissance use as evolved under this new application of the systems approach. It is a system designed for specific uses based on detailed analyses of requirements. Since it is intended for more than one use or purpose, it provides for interchangeable installation of different components, each best suited to a particular purpose. In accordance with the established requirements, the system is designed to supply coverage of a reasonably large area showing only major detail and to supplement this by coverage of only a relatively smaller selected area with fairly fine detail to be used at high altitudes. It is also planned that for other purposes it shall provide coverage of limited areas with extremely fine detail for use at very low altitudes. For the high-altitude mission, an array of three short-focus, wide-angle cameras is used for the large area coverage, and an arrangement of two long-focus, large-format cameras in a split vertical configuration is used for the small area detailed coverage. The short-focus camera array provides compensation for image motion due to the plane's forward velocity and has a fast maximum cycling rate so that this group may be used in an emergency at low altitudes. The group is carried in a single fixed antivibration type of mount. The attitude of the group with respect to the vertical (as indicated by the vertical reference of the plane's navigation system) is automatically recorded at instant of exposure to provide a degree of control for the relatively rare photogrammetric uses of the photography. The long-focus cameras also provide image motion compensation to make up for forward aircraft speed. They are carried as a group in a single stabilized mount to eliminate angular motions from gusts and maneuvering of aircraft. These cameras are of the autocycle type. During operation the heavy masses of film on the spools are kept rotating continuously at the proper rate to complete one cycle just in time for the start of the next. All mechanism motions are counterbalanced in order to keep disturbances from dynamic reactions to a minimum. Diaphragm and shutter-speed settings are automatically controlled to follow a prearranged program that will give the shortest exposure time for each light condition, minimizing any image degradation due to blur. All cameras in a group are synchronized to trip together, so the nadir point will be common to all photos taken by the group.

For the low-altitude mission, these cameras are removed and replaced by a group of five short-focus, small-format, small-film cameras. These are mounted in an array in several fixed-attitude, antivibration mounts to provide complete coverage crosswise to the flight line from horizon to horizon. The cameras are capable of extremely high cycling rates and also provide coordinated image motion compensation to minimize blur. Since it is impossible to compensate correctly for all parts of the image, a high shutter speed is provided. This, in turn, requires use of a fairly fast lens in order to provide necessary image quality and still handle the range of expected light conditions. These cameras are

also autocycle in operation in order to minimize dynamic reactions and reduce strains in the mechanism. Shutter and diaphragm settings are here also controlled to give the shortest exposure time permitted by each given light condition. The entire system is carried in a temperature-stabilized compartment to ensure maintenance of calibrated focus settings.

In both the high- and low-altitude configurations, information existing in the plane's navigation system—such as the plane's geographic position, heading, altitude, etc.—is recorded automatically at time of each exposure for later identification of the photo. Each camera is supplied with intelligence on terrain light conditions by an automatic sensing system. Each camera is also supplied with intelligence on the proper image motion and cycling rate and with synchronizing intelligence from a central master rate control system. Basic intelligence on altitude above the terrain and ground speed necessary for camera rate control comes from an optical scanning system at low altitude and from the plane's navigation system at high altitudes. The entire system is fully automatic in operation. The operator or pilot, as the case may be, merely flips a switch to select the group of cameras he wishes to use and flips another to start them operating.

In the evolution of this system, through the systems approach, major emphasis has been placed on certain design considerations. First from the user's viewpoint are considerations of Optimum System Performance and Maximum Reliability. Optimum system performance is achieved by evolution of a well-balanced overall system design, selection of optimum lens focal length to yield adequate detail size consistent with the required detail size and with the film's resolution capabilities, and preservation of image quality through temperature control and by minimizing of motion effects. Maximum reliability is achieved by reducing system complexity, avoiding the use of unreliable elements, using positive acting devices, planning circuits to reduce to a minimum the number of soldered connections and disconnects and contacts, and providing the maximum degree of accessibility for ease of servicing and preventive maintenance. Reliability potential is also greatly enhanced through the careful attention to human engineering factors from both the operation and maintenance standpoint. Automatic rather than human operation has been provided for the most part. Maintenance philosophy has followed a "go-no-go" type of checking procedure with a package replacement plan and with a packaging arrangement that places functionally related components together to minimize chances for human error.

A second point of major emphasis concerns the relationship of the photo system to the other parts of the overall system, particularly the aircraft itself. Of prime importance here are considerations of size and weight, power consumption, and environmental control. To keep size and weight to a minimum requires constant vigilance from the inception of design, with special attention to elimination of all features not entirely necessary. Minimum power consumption is the result of complete analysis of the various loads and careful evaluation of the different methods of supplying power. Environmental control involves integration of the photo system's environmental control requirements with the aircraft's environmental control system.

A final point of major emphasis concerns the manufacture of the system, with considerations of cost and producibility predominating. Here a constant campaign must be waged against tight tolerances and overrefinements. In each case the effect on system performance must be the determining factor.

These considerations have been the general design aims. The means of accomplishment have been through the application of a number of philosophies that have gradually evolved and have become inseparably associated with the systems approach. Of chief importance, among these, are the following:

(1) Balanced Design—design to meet but not exceed requirements.

(2) Growth Potential—select design to meet requirements easily so it can subsequently be pushed further.

(3) Optimum Design—design to accommodate essentially all conditions but stop at point of diminishing returns.

(4) Equalized Performance—evaluate and design to equalize effect each contributing component has on overall performance.

(5) Evaluation of Alternate Functional Approaches—select for greatest overall advantage.

(6) Elimination of Nonessentials—include in system only what is needed.

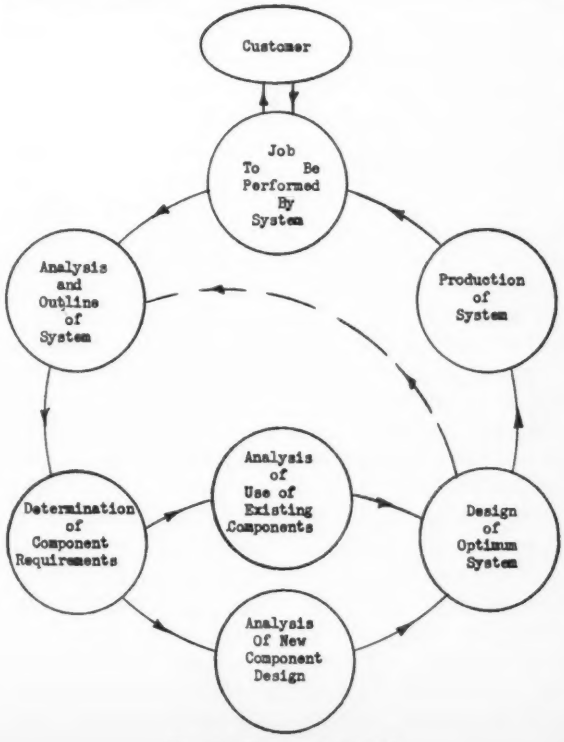
Customer
Job To Be Performed By System
Analysis and Outline of System
Production of System
Analysis of Use of Existing Components
Determination of Component Requirements
Design of Optimum System
Analysis Of New Component Design

FIG. 2. Systems approach.

(7) Integration with Other Systems—design to share functions, input intelligence, etc.

(8) Functional Packaging—package together functionally related elements as far as possible.

Each of these philosophies requires some elaboration in order to illustrate its effect on the design of the photo system.

Balanced Design has been placed first as it is one of the most important and useful concepts. It is, of course, important to meet the necessary system requirements, and this, naturally, means that each component must meet its own requirement. What is not so obvious, however, is that it usually imposes penalties on the overall system to permit any component or subsystem to carry the apparatus to exceed its requirement. Wherever it involves any additional complexity, weight, power, or cost, or other penalty, it should certainly be avoided. This implies, incidentally, an extremely good evaluation of the requirement, and this again is an inherent function of the systems approach. For example, in the case of the system described, it was assumed that the requirement for small area coverage was further defined to the extent of establishing the approximate area and the detail size that must be resolved. This, in turn, resulted in the decision that two cameras of a certain lens focal length, format size, and film capacity would satisfy this requirement. To attempt to resolve finer detail would have required a longer focal length, and then to cover the area would have required a third camera and a larger film capacity in each one.

Growth Potential is a factor that must always be carefully weighed throughout the evaluation and design stage of a system. The achievement of a good growth potential in a system without incurring immediate penalties requires the employment of a considerable degree of both ingenuity and good judgment. Even before that, it requires a good projection of all the trends and prediction of future development of the overall system of which the photo system is only a part. Then, when the probable direction of future growth has been predicted, it means selecting designs that give present required performance at operation well below their saturation point. The choice of autocycle operation for the cameras of the system described is an example of this. This type of mechanism easily provides the cycling rates necessary for the present system without even approaching the maximum rate capabilities of the mechanism. By the simple application of a larger motor and higher power input, higher rates could easily be handled in the future.

Establishment of an *Optimum Design* is one of the most important philosophies of the systems concept. It, again, requires the exercise of excellent judgment in order to pay off. In the application of this philosophy to present photo systems, it has involved many laborious statistical analyses of many of the operating and surrounding conditions. It has resulted in complete elimination of several features, at a considerable saving of cost, weight, and complexity, when the analyses showed these features to have an insignificant effect on performance in all but a negligible percentage of the operational time. The feature of single-shot operation, for instance, has been omitted in some cases on this basis.

The philosophy of *Equalized Performance* offers the systems designer the opportunity to effect both significant cost savings and gains in overall performance. In recent photo systems, for instance, several of the expensive high-performance electronic servos in the exposure control function have been replaced by less expensive relay-type servos. Here the high performance of the expensive units was a pointless refinement because the input information was of a low order. On the other hand, by improving the accuracy of the input sensing device, the overall performance is improved—even with the less expensive servos.

The *Evaluation of Alternate Functional Approaches* in the early consideration of the system and the selection of the one offering the greatest overall advantage are obvious design tools inherent in the systems approach. As applied to recent photo systems, this evaluation and selection have resulted in considerable savings in weight, complexity, and cost. A common power supply for all electronic components of the system, for instance, has been found to have advantages over the use of individual supplies in each component.

Elimination of Nonessentials requires a close scrutiny of the contribution of each component to overall system performance and capabilities. This contribution must be examined in the light of mission requirements, and the deletion of unnecessary functions or apparatus must be pressed to the limits of practicality. As an example, in the system described previously, the optical scanning device used at low altitude for detection of intelligence for camera rate control would be removed from the installation in changing to the high-altitude configuration.

Integration with Other Systems can produce substantial savings in weight, space, complexity, and cost when properly handled. This requires a careful consideration of the types of inputs needed and the manner of their availability from other systems to prevent duplication of equipment. In present systems input intelligence—such as plane's altitude, ground speed, heading, present position, roll and pitch reference angular data, and other inputs—are derived from central input sensing devices common to all systems.

Functional Packaging can be productive of greater flexibility and reliability for the system. Conversion from one type of mission to another is accomplished more rapidly and with less chance of error when the major units of equipment have their related equipment packaged with them. Reliability is increased since many of the electrical connections can be eliminated. The human engineering factor is improved as it is easier for maintenance men to isolate any trouble that may develop. In most recent cases considerable advantages of these types have been found by packaging the various servo-amplifiers in the same units with the servos them-

selves throughout the system—in the cameras, in the mounts, and in the various functional parts of the control system.

System performance and the effects of the system approach on system performance deserve special mention and discussion. Generally speaking, the prime factor of importance in measuring the net value of a photo-reconnaissance system is its information-recording ability—how well it brings back the right amount of the right kind of information. For certain purposes the demands on information content have exceeded the capabilities of the photo system to provide it, and it has been necessary to analyze what might be done to improve it. In this effort it is fairly obvious that the systems approach can pay off by showing up the areas where greatest losses occur and permitting a concentration of effort on these areas.

Starting with the basic image quality obtainable with the lens-camera combination in the laboratory, losses occurring in a practical system in normal operation fall into four general categories: (1) changes in location of the image (focus shifts), (2) motion of the image, (3) general deterioration of the image, and (4) failures of the film and processing system to record it properly. Work has been done independently by many organizations on individual causes contributing to the losses in all of these areas. By combining these individual studies and analyzing the combined effects on the entire photo system under consideration, predictions have been made of probable performance and its dependence on various alternate choices of portions of the system. In several areas positive steps have also been taken to try to reduce the worst of the losses.

In the case of mapping systems, an additional factor—the preservation of the geometric relation—is as important as information content. This involves an additional set of factors which must be reckoned with in the design of a mapping system. Design considerations of the air-borne photo-mapping system also involve the type of systems to be used in the plotting and laboratory map-making operations and include the necessary features to permit proper and effective cooperation with these. Fortunately, the systems approach has been applied for a number of years and is continuing to be employed in new development in this phase of the activity. The present highly perfected state of the mapping system art and the rate of continuing progress are good evidence of its effectiveness.

The advantages of the system approach are many and important. In thoroughly considering a concept as basic as this, however, thought should be given to any possible shortcomings. One such possibility is the fear that this concept might soon result in the production of a large number of different pieces of equipment to do essentially the same job but in different systems. It is probably true that if development were permitted to run away completely uncontrolled, this sort of thing could happen. However, there are a number of influences that tend to keep the situation in line. First, there is the monitorship of the customer—the cognizant Government laboratory. Second, there is the economic situation itself. The element of competition, always present, forces any manufacturer to utilize available designs that are suitable for use in new systems. Third, the technological situation tends to foster unification rather than diversification. Review of the requirements of a fair number of different systems indicates that for a certain time period the same performance requirements, the same requirements for certain features, the same need for emphasis on maximum reliability and minimum size, weight, and power, and the same kind of environmental conditions which exist in connection with one system also exist in the others. Certainly we shall never avoid a certain amount of obsolescence as system requirements change with time under any concept. Nor should we ever want to put a stop to the advancement of the art. It seems evident, however, that, once we have produced a new reconnaissance system that will well satisfy a certain new requirement, we shall be able to make use of it almost *in toto* in many other applications directed toward the same end use and for the same time period. In fact, contrary to having a tendency to produce many types of equipment for the same job, it seems now that the systems approach through the application of more extensive research into the basic overall requirements is beginning to point the way toward consolidation of many existing equipment types into relatively few.

From all of the foregoing, it may be seen that the effects of the systems approach on the design of photo-reconnaissance systems are broad and far-reaching. Its intelligent application offers outstanding advantages to the customer or user, to the other systems (particularly the aircraft), to the manufacturer, and to the taxpayer.

From the standpoint of the customer, it may be said that the system is designed with the user in mind. He reaps the benefits of higher overall performance through a system more ideally matched to his job, and with greater inherent reliability. For example, on the basis of what has been done in a specific case it appears possible to reduce the number of tubes, contacts, connectors, and circuit joints by 50 to 75 per cent and thus realize considerable improvement in reliability.

The aircraft producer has obtained significant advantages in reduced weight, reduced volume, and lower power consumption. Again, as indicated by a typical case, reductions of the order of 50 to 70 per cent in weight, power, and volume appear possible while still performing an equal or larger job. Additional advantages accrue in the form of easier manufacturing and installation problems through a system better matched to the aircraft.

The system equipment manufacturer benefits in the form of fewer manufacturing difficulties, reduction in servicing problems, and lower cost.

And, finally, the taxpayer benefits. A better, more effective, reconnaissance system and the increased potential for more effective use of our weapons, in effect, buys him better national defense at lower cost.

Problems of Aircraft Construction for Electronic Magnetometer Survey or Detection

H. C. WROTON*
The Glenn L. Martin Company

THE NEED for a "systems engineering" approach to installation design is emphatically illustrated by the air-borne electronic magnetometer. This is an extremely sensitive device, used for aerial surveying and mineral prospecting and for the detection and location of hidden magnetic objects such as enemy submarines. The magnetometer detects extremely small changes in the magnetic field in which it operates and, as a result, is more seriously affected by the form and structural design of the air frame in which it is carried than almost any other type of electronic equipment. The need to incorporate the peculiar requirements of the magnetometer into the earliest aircraft design conceptions can be determined on a strictly economic basis. Many years of effort, costing many millions of dollars, have been spent in adapting existing air frames to carry magnetometer equipment successfully.

Early use of the design information that has been accumulated can eliminate or greatly simplify the problems and at a small fraction of the cost of later adaptation. At The Glenn L. Martin Company, we have gained such an appreciation of these factors that even the most superficial studies of new aircraft and weapons system designs using magnetometers incorporate those factors that will guarantee performance without the necessity for the prolonged and expensive development and test programs needed for recently adapted installations.

In this study, I wish to explain the specific problems encountered in air-borne magnetometer installation and the effective methods for solving them. But, before I proceed, I imagine that there may be some readers who have not had experience with this equipment. My own introduction to the amazing and sometimes exasperating characteristics of air-borne magnetometers is still fresh enough in my memory to make me quite sympathetic to anyone just meeting this device, and so I ask the indulgence of the experts while I review briefly the principal features of the equipment.

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* Head, Magnetics Group, Electronics Department.

Magnetometers are instruments that generally measure both the strength and the direction of magnetic fields, but most air-borne types measure only strength. They are self-erecting by means of servo-control systems so that they always measure the maximum vector of the field in which they operate. Some of today's more precise air-borne magnetometers are so sensitive that they can detect the magnetic fields created by the shoe nails of a man several feet away.

When you consider installing such equipment in an airplane, a host of potential sources of interfering magnetic fields comes to mind. The engines, landing gear, motors, hydraulic cylinders and pumps, electronic equipment, control cables, and structural components all may have strong magnetic fields. These magnetic fields are complex and cause local distortion of the field that the magnetometer is intended to measure or detect.

The major effect of the interfering magnetic fields from parts within the airplane is to add to or reduce the apparent amplitude of the ambient field. In geographical surveying, this affects the absolute accuracy of the measurement. Some magnetometers detect only changes in the ambient field strength. This type of magnetometer is not affected by the change in absolute field strength cause by interfering fields, as long as these fields remain constant.

Airplanes, however, are continually maneuvering in flight. The result is that the directions of the fields within the airplane change with position and attitude, while the external, earth's magnetic field remains fixed in space. Since the magnetometer always measures the amplitude of the total field passing through it, this rotation of the field vectors from the airplane, with respect to the fixed earth's field, causes a change in the total field amplitude proportional to the amplitude of the maneuver. It is necessary, then, that all fields from the airplane be reduced or neutralized, so that maneuvers will produce changes in the total field less than the sensitivity level of the magnetometer being used.

Fortunately, distance has an important effect on the strength of magnetic fields. The field strength of a

magnet varies approximately as the inverse cube of the distance to the magnet. This means that the sensing element should be as far removed as possible from magnetic parts. A small magnetic part near the detector may interfere as critically as a large part farther away. A minimum distance of 5 to 15 ft. might be established for small magnetic parts such as screws and nuts. Beyond this, parts having stronger fields could be tolerated, provided the relationship of field strength to distance was determined and found to be within the sensitivity limits demanded of the installation.

Because of the accumulated design information, it is now possible to formulate rules for the location of magnetometer detecting elements and for the choice of structural and other materials to be used in the vicinity of the detecting equipment. Suitable nonmagnetic high-strength structural materials are now available for use near the magnetometer detecting element, and materials having weak magnetic properties can be used for larger parts located further away, so this problem is not especially troublesome. Proper location of the detecting element is more difficult.

The placement of other equipment—particularly in military aircraft—frequently conflicts with the location of the magnetometer. A less-than-optimum location can be compensated for, but the more the location of the element is compromised, the more difficult this compensation is to apply and maintain.

Three types of sources of magnetic interference are associated with the design of the air frame. The first type produces permanent magnetism and originates in hard-steel parts that have become magnetized either as a result of manufacturing process or by coming in contact with a magnet or magnetized part or tool.

A second characteristic source of magnetic interference produced by air-frame parts is that which is caused by induced magnetic fields. These are generally associated with soft-iron parts like transformer cores and shield covers—although they also occur, to a limited extent, in hard-steel parts. Induced fields are generated in magnetic materials by the action of an external field. The strength of the induced fields is a function of the direction as well as the strength of the external field. A solenoid plunger is a good example of a device that works on the principle of induced magnetism. Until a current sets up a field in the solenoid coil, no appreciable magnetic field is present in the plunger, but as soon as the current is turned on, the plunger becomes a magnet and is attracted to the pole piece. The field set up in the solenoid coil has induced a local field in the plunger. By this same principle, the earth's magnetic field induces local fields in the airplane. In the case of truly soft iron parts, the induced field may be the only one present; but in hard-steel parts, which already have some permanent magnetism, the induced fields merely aid or oppose the permanent magnetism, depending on the relative direction of the earth's field. The induced fields in hard-steel parts are generally only a fraction of the normal permanent ones.

The interference produced by induced magnetic fields is susceptible to reduction by distance in the same manner as that from the permanent fields. Neutralization or compensation for them, however, requires a completely different approach, as will be shown.

A third source of interference—also susceptible to reduction by distance but necessitating a third method of compensation where required—is that produced by eddy-current fields. These occur in all of an aircraft's skins, ribs, frames, and other structural units without respect to the magnetic characteristics of the materials from which they are made. They require only electrical conductivity and airplane maneuvers to exist, and they are generated in the same fashion as the currents produced in a coil or loop of wire rotating in a magnetic field. An electrical conducting path is formed around the outside edge of the sheet metal of an aircraft skin or rib. As the airplane maneuvers, an electric current proportional to the rotational velocity is produced in the magnetic field of the earth. The flow of current creates a magnetic field in a direction perpendicular to the plane of the sheet or conducting loop.

These eddy-current fields are often not as large as the permanent magnetism ones, but, since they are related to aircraft maneuvering rates, they are extremely serious. When an airplane is flying at the low altitudes used for magnetic surveying or detection, turbulent air, which increases the amount of maneuvering, is often encountered.

I have now outlined the three types of magnetic interference which can be reduced by proper air-frame design. A fourth source should be mentioned, although it is not so directly related to air-frame construction. This interference is caused by electrical power wiring circuits, which contain loop-type current paths. These circuits produce a kind of permanent magnetism field, which varies in strength with the amount of direct current flowing. This interference will be eliminated if ground return wires are used instead of the air-frame structure for the negative current path back to the power source.

It has been noted that distance is a good cure for all types of magnetic interference in air-borne magnetometer installations. While this is quite true, it is often difficult to achieve. To escape all four types of interference, the detector would have to be placed 100 or more feet from the airplane. There are systems of this type in which the detector is towed behind the ship, but they have problems of their own and have not been widely accepted.

For inboard installations, then, we must expect to find it necessary to compensate or neutralize some degree of interference. The cost and time required for this compensation are directly related to the complexity of the fields. Anyone who has been associated with such work knows the importance of minimizing the need for compensation.

In several recent installations with complex interfering fields the necessary flight testing for compensation has amounted to almost as much as that required

for all aerodynamic, power-plant, and structural purposes on the aircraft.

As mentioned before, the three basic types of interference require three methods of compensation. All three work on the principle of cancellation. Once they are installed and adjusted, they produce a fixed amount of compensation, which need not be varied unless the interference itself changes. Each interfering field is directly opposed by a compensating field at the location of the detector. Naturally, the compensating fields must act the same as the interfering ones, so that the cancellation is correct under all conditions. This means that the compensators must produce permanent, induced, and eddy-current magnetism of the proper amplitude and direction.

The permanent magnetic fields of the airplane are compensated by carefully controlled direct current passing through coils of wire. These coils, which produce permanent magnetism, are arranged in three mutually perpendicular planes, so that interfering fields in any direction may be cancelled. To save weight, space, and power, the coils are placed close to the detector. The compensator is generally adjusted in flight, although an initial adjustment can be made on the ground in certain types of installations. Independent rolling, pitching, and yawing maneuvers are performed to permit the currents in the three coils to be separately adjusted. It has been proved that the smaller the interfering field, the more quickly and more accurately the compensating currents can be set. These compensators must be set for individual airplanes because the permanent magnetism fields are never precisely the same.

Compensation for induced magnetism is accomplished by soft-iron strips or balls placed near the detector unit. The small physical size of these strips or balls makes them relatively easy to install; but induced-field compensators are extremely critical and also require flight testing, so reduction of the magnitude of all induced fields is an important objective. The effectiveness of induced-field compensators is generally consistent from airplane to airplane of a given production model.

The eddy-current fields are the most difficult to compensate for, and the compensators usually require the most weight and space of the three types. The compensating fields themselves must be generated by eddy-currents in plates, sheets, or rings of nonmagnetic metal located near the detector. These compensating sources must lie in planes that are parallel to those of the interfering sources.

The strength of the compensating fields is determined by the plan form, thickness, and conductivity of the metal used. Eddy-current fields are difficult to predict accurately and must be finally tested in flight. It appears, however, that analytical predictions can adequately establish compensator dimensions and that a compensator design, based on tests of an accurate prototype, will be effective for all aircraft of that model.

A discussion of Figs. 1–8 will help illustrate the points I have made.

Fig. 1 illustrates the inverse cube rule—by which we can approximate the effect on interference of increased distance between the detector element and a magnetic part with fixed field strength. The abscissa shows, in feet, the separation between the detector and the part, and the ordinate shows the percentage of noise produced by a specific motion of the part; 100 per cent is arbitrarily established as the signal level obtained at a 3-ft separation.

By applying the separation rule to an airplane, we can see that, for magnetic parts to produce no more than a specified, maximum interference level, we have a pattern of permissible locations. The large magnetic parts must be widely separated from the detector head, and only the smallest may be close to it. This means that the detector must be remotely located.

In Fig. 2, two airplane designs are shown with a variety of remote magnetic detector locations. On the airplane with the conventional tail there are three positions: a wing-tip pod, a fin pod, and a tail-cone extension. On the T-tail design there are three others: a tail bullet-fairing extension, a wing pylon, and a faired, submerged wing pod.

All of these installations involve important structural and aerodynamic considerations, and they are not just theoretical, untried installations. All of them have been built, and most of them are flying today.

For the remaining figures, I shall describe the general features of each location and indicate the proper placement of the eddy-current compensators. These positions are not arbitrary but are established on known principles. Substantial deviations from the illustrated positions will not produce acceptable results.

In all the installations, a set of coils for permanent magnetism compensation can be installed close to the detector. Induced compensation strips or balls can generally be applied without serious space problems.

The most important factor to note, of course, is the relative need for compensation. Although the location and general form of the compensators can be determined, the difficulty of accurate size determination and adjustment is a direct function of the strength and complexity of the interferences. The best location will always be the one requiring the least compensation.

In Fig. 3, the large magnetic parts nearest the wing-tip pod are the engine, the landing gear, and the equipment in the fuselage. If the airplane is a military type, the bomb bay also contains sources of interfering magnetic fields whose separation cannot exceed one-half the wing span of the ship. The permanent, induced, and eddy-current fields generated by the wing itself require a high degree of compensation.

An insulating section of plastic between the wing and the pod would help, but it would have to be several feet long to do much good. Eddy-current compensation would almost surely be necessary.

The eddy-current compensation takes the form of a plate or ring, parallel to the plane of the wing but located directly over the magnetometer. To fair in this sheet, which must be several inches from the detector, a

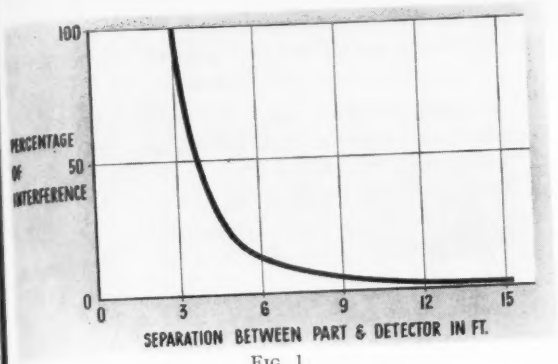


FIG. 1.

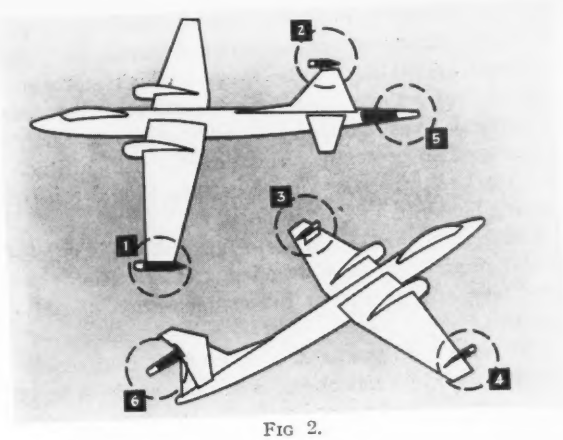


FIG 2.

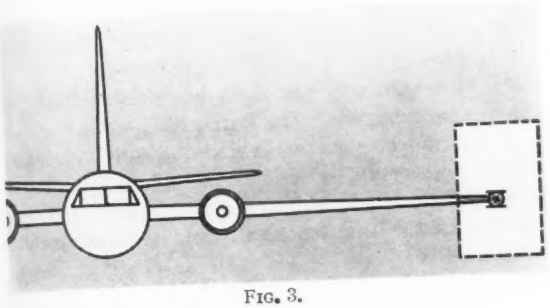
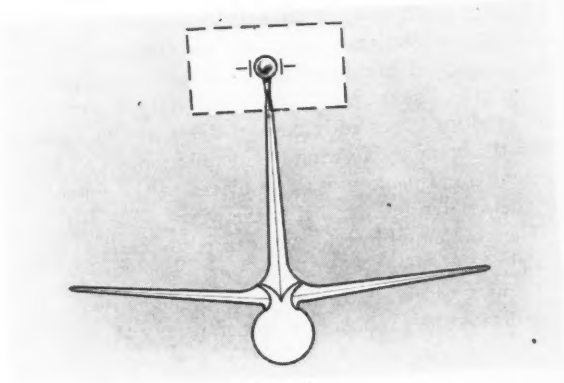


FIG. 3.



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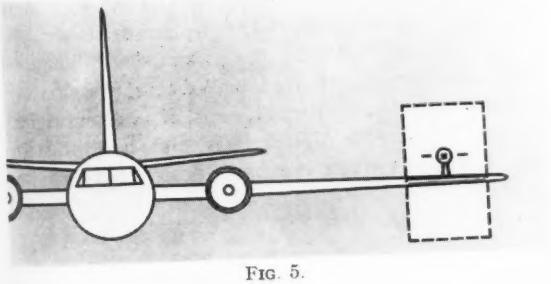

FIG. 5.

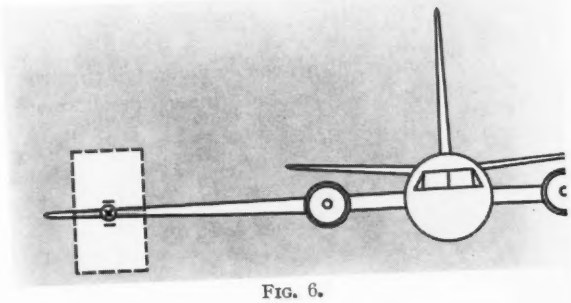

FIG. 6.

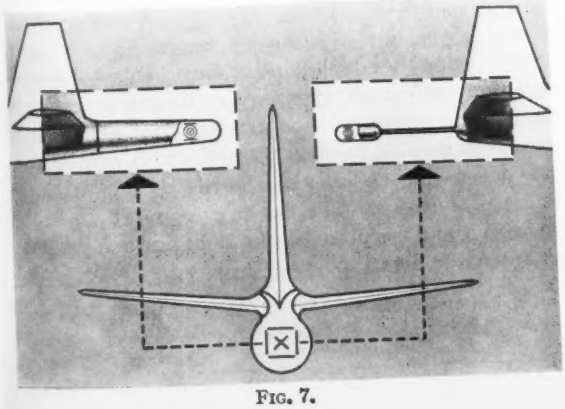

FIG. 7.

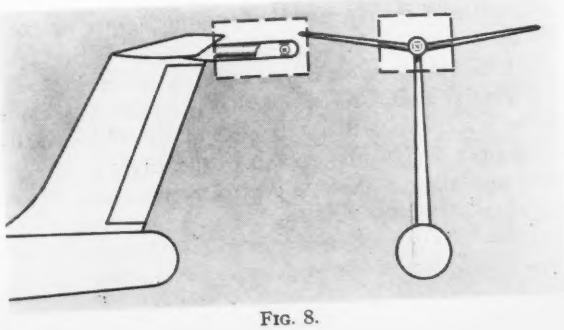

FIG. 8.

large pod would be needed. This would obviously increase the structural and aerodynamic problems. One other detrimental factor also exists in this installation. Rolling the airplane would cause interference because of vertical translation of the detector. The earth's magnetic field strength varies directly with altitude. The vertical translation of the detector would cause a varying field strength to be measured.

Considering Fig. 4, in the fin-tip position, it is relatively simple to achieve an adequate separation from large magnetic parts, but full compensation of eddy-current fields is difficult.

The vertical fin produces eddy-currents that require compensation by vertical plates or rings at the sides of the detector. Eddy-current effects can sometimes be caused by the horizontal tail surfaces also. Compensation for these effects requires horizontal compensators located as shown in the figure.

In Fig. 5, the wing-pylon installation is similar to the wing-tip installation, except that the distance from the engines and other magnetic parts is reduced. The wing is also in a different position relative to the detector and will produce larger eddy-current fields at the detector than the comparable wing-tip installation. The eddy-current compensation must be placed at the side of the magnetometer and parallel to the wing.

The problem of interference caused by vertical translation of the detector is also present.

Turning to Fig. 6, in the faired submerged wing-pod installation the problems are substantially the same as for the wing-tip installation. Use of a nonconducting wing section to reduce eddy-current fields would be difficult, however, and so a greater amount of eddy-current compensation would be required.

The problem of vertical translation during roll maneuvers is inherent in the submerged wing-pod installation.

Fig. 7: For aircraft with conventional tail construction, the extended fuselage "tail-stinger" installation is best. The distances to magnetic parts can be made great, reducing permanent and induced magnetism to values relatively easy to compensate.

If the fuselage extension is nonmetallic or, in the case of a retractable installation, if the retractable tube is of small diameter, the eddy-current fields may be made small enough not to require compensation.

If sufficient distance to avoid interfering eddy-current fields cannot be incorporated, the compensation can still take the convenient, box-type form shown in the figure, and, in all cases, the magnitude of the fields requiring compensation will be reduced from those of the preceding installations.

Fig. 8: Many new airplanes are making use of the T-tail, in which the horizontal tail surfaces are attached to the top of the vertical tail. The general rule for any tail location of the magnetometer is to place it directly behind the intersection of the tail surfaces.

This allows the use of an extended "bullet fairing" as is shown in the figure. The fairing should be made to locate the detector as far behind the tail surfaces as possible and should include nonmetallic materials to reduce eddy-current fields. A retractable installation could be used if it is structurally and aerodynamically feasible.

If the distance between the detector and the aircraft metal structure is not sufficient to eliminate all eddy-current interference, compensation can be applied in box form, with the vertical and horizontal plates or rings being located in a square pattern. (See Fig. 2.)

These, then, are the major choices of detector locations which are available to the airplane designer. All can be made to work, but the cost of developing any installation requiring a great deal of compensation will generally exceed many times the cost of a better original design. This factor of extremely high cost must be given full credit when the basic design compromises are made.

Past and Present Automatic Flight Control Development

(*Continued from page 61*)

means of control equipment in order to compensate automatically for aircraft configuration, gross weight, and local wind conditions. The two methods that appear to be the most feasible for effecting this control are (a) changing the air-speed reference of an air-speed control at a rate proportional to angle of attack error and (b) using a signal proportional to the angle of attack error to actuate a throttle control system, this latter method being the simplest of the two. It has also been found desirable to compensate for the effect of thrust on lift during approach and flare-out by a signal cross-feed from throttle position to pitch angle and to provide means for closing the throttle during the later stages of flare-out. The device has proved to be an interesting and useful tool in the flight research program on automatic flight.

Application of Electronic Simulation Techniques to the Development of Airplane Flight Control Systems

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Introduction

DURING THE PAST 10 YEARS one of the most outstanding and useful tools developed to aid in the design of aircraft has been the electronic analog computer. This device, in various forms, is now in general use during all stages of aircraft flight control system development, from preliminary studies through airplane flight testing. It is the purpose of this paper to discuss the application of the analog computer in engineering an airplane flight control system. Application during each phase in the development of an airplane will be discussed with the aid of illustrated examples showing results of tests conducted with actual airplane flight control systems. The paper will be confined to application of analog computers and will not include discussions of computer design or airplane flight control system design details. However, for illustrative purposes a few control system designs will be discussed briefly.

Procedure in Synthesizing Airplane Flight Control Systems

In order to provide proper orientation concerning the use of the analog computer, a brief description of the entire synthesis procedure is presented in Fig. 1. With the inception of a project, customer requirements, past company experience, contract data, and other information are combined in a preliminary analysis providing the tentative requirements and configuration for the flight control system. In this paper the "flight control system" includes all components, systems, and parameters affecting the flight control of the airplane. After the tentative system requirements and configuration have been established, an analog computer study is made of the complete system, with all components and aerodynamic characteristics represented by electrical networks. In this system analysis, transient responses are obtained as the system parameters are varied, until an optimum system is obtained as represented on the analog computer. This function of continuous observation of results as parameters are varied is shown in Fig. 1 by the servo block diagram. The end result of this step is the establishment of firm component requirements.

The components are then designed, fabricated, tested, and in some cases modified until the component requirements are met. The actual components produced by this step are then assembled on an airplane test stand, which consists of a steel framework on which is mounted the actual control system of the airplane with the aerodynamic response characteristics represented by an analog computer. The control surface deflections are measured and introduced electronically into the analog computer, which instantaneously determines the response of the airplane and feeds this information back into the airplane flight control system sensors. With such a test stand a human pilot can "fly" the airplane in the laboratory. Control column feel is accurately provided by force-producing devices attached to the control column, and visual response data are provided through instruments mounted in the simulated cockpit. The chief factor limiting the degree to which simulation can be attained is the lack of controlled position of the human pilot—for example, the pilot does not undergo normal accelerations as would be the case in an actual flight. Another limitation is the difference in pilot response due to pilot tension associated with actual flight conditions. During the flying test stand simulation program, differences between performance of actually installed components and previously analoged characteristics of the components are detected, and the system is changed as necessary to provide a control system with response characteristics that satisfy its requirements. Simulator tests are also conducted in studying possible results of equipment failures.

The system then passes through a production design manufacturing stage and is installed on a flyable airplane. Here, again, the analog computer is used. The test stand simulator program is repeated with the

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* Chief, Flight Controls and Servo.

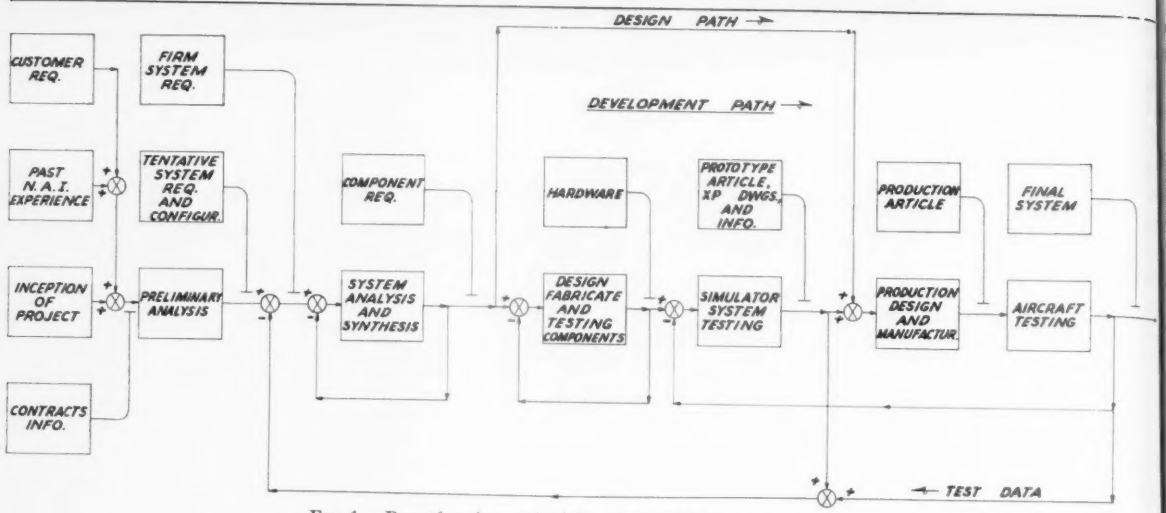


FIG. 1. Procedure in synthesizing airplane flight control systems.

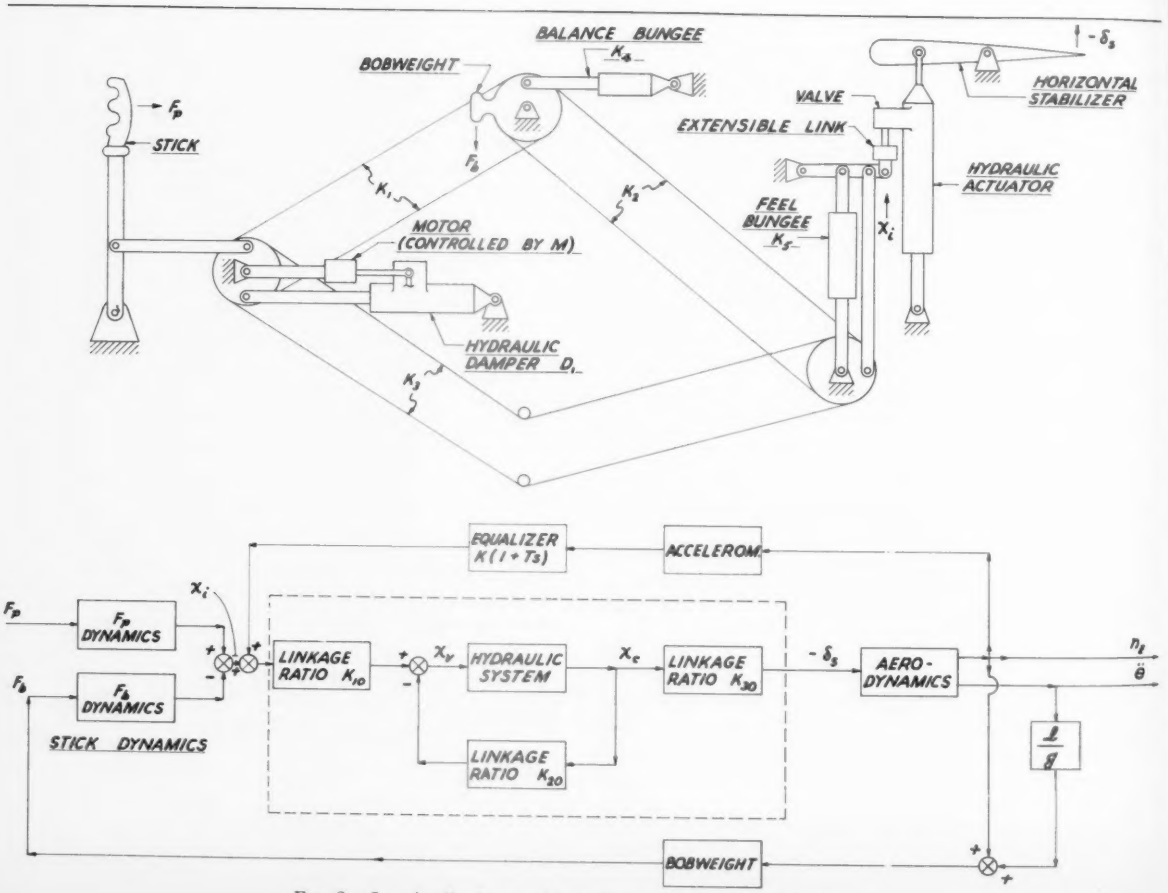


FIG. 2. Longitudinal control system schematic and block diagram.

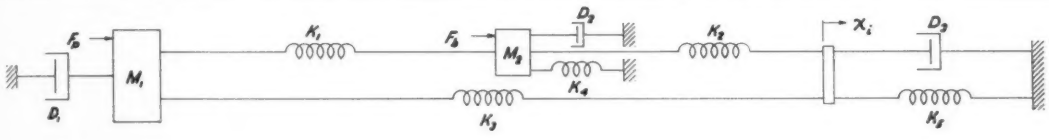
control system and steel framework replaced by the airplane itself, with the control surfaces loaded as required to simulate aerodynamic forces. The analog computer is again used to determine airplane response to surface deflection and to introduce this information into flight control system sensors. Actual airplane sensors are used when practical. However, on occasions such as those in which inertia references are important, the sensors are mounted on testing tables on which airplane orientations can be reproduced. This step in the procedure indicates any performance differences caused by airplane installations as compared to test stand installation.

During the subsequent flight-test program, most of the steps of this procedure may be required again, provided unforeseen problems arise. For example, the system requirements may be changed as a result of the flight-test program, or new parameters or degrees of freedom which were not included in the aerodynamic analog computer may become important. In solving problems such as this, concurrent application of the analog computer and flight simulators along with airplane flight testing results in a considerable saving of flight-test hours.

The procedure outlined above is regarded as an ideal objective and cannot always be carried out. Delivery schedules may require reducing the time spent in one procedure step or may require parallel activity in conducting steps—e.g., production design may be conducted concurrently with the simulator program. This possibility is indicated in Fig. 1 as the Design Path. Another deviation from the procedure might be the elimination of testing of an actual air frame connected to an analog computer. This can be done by confirming by tests that the dynamic characteristics of the airplane system are the same as those of the test stand systems. If they are identical, it is obvious that the airplane test can be eliminated. Several feedback paths have been omitted from the figure for simplification purposes; however, these are not necessary for the purpose of this paper.

Analysis

To illustrate the procedures involved in the synthesis of airplane flight controls, the longitudinal control system of Fig. 2 will be used. With this system, the pilot controls the airplane by exerting a force on the control



$$\frac{x_i}{F_p} = \frac{M_1 K_2 s^3 + D_1 K_2 s + K_1 K_2 + K_1 K_3 + K_2 K_3}{\alpha_5 s^5 + \alpha_4 s^4 + \alpha_3 s^3 + \alpha_2 s^2 + \alpha_1 s + \alpha_0}$$

(α_1, α_2, α_3, α_4 AND α_5 ARE FUNCTIONS OF M_1, M_2, D_1, D_2, D_3, K_1, K_2, K_3, K_4 AND K_5)

STICK SYSTEM DYNAMICS
FIGURE 3-A

1. $$\left[\left(\frac{-mV}{gs} + \frac{c}{2V} C_{L_q}\right)p + C_{L_0} \tan \gamma_0\right] \theta + \left[\left(\frac{mV}{gs} + \frac{c}{2V} C_{L_{\dot\alpha}}\right)p + \left(C_{L_\alpha} + C_{D_0} - C_{L_0} \tan \gamma_0\right)\right] \alpha + \left(2C_{L_0} + MC_{L_M}\right)\left(\frac{V_1}{V}\right) = C_{Z_{\delta_E}} \delta_E$$

2. $$\left[\left(\frac{I_Y}{gsc}\right)p^2 - \left(\frac{c}{2V} C_{m_q}\right)p\right] \theta + \left[\left(-\frac{c}{2V} C_{m_{\dot\alpha}}\right)p - C_{m_\alpha}\right] \alpha - \left(MC_{m_M}\right)\left(\frac{V_1}{V}\right) = C_{m_{\delta_E}} \delta_E$$

3. $$\left[C_{L_0} + \left(\frac{c}{2V} C_{D_q}\right)p\right] \theta + \left[\left(\frac{c}{2V} C_{D_{\dot\alpha}}\right)p + \left(C_{D_\alpha} + C_{D_0} \tan \gamma_0 - C_{L_0}\right)\right] \alpha + \left[\left(\frac{mV}{gs}\right)p + \left(2C_{D_0} + MC_{D_M}\right)\right]\left(\frac{V_1}{V}\right) = C_{X_{\delta_E}} \delta_E$$

4. $$n_z g \cong -V\dot\gamma - g$$

5. $$\gamma = \theta - \alpha$$

BASIC LONGITUDINAL EQUATIONS OF MOTION
FIGURE 3-B

column.* The reaction force that he feels is caused primarily by the hydraulic damper, D, the bobweight, and the feel bungee, K_s.

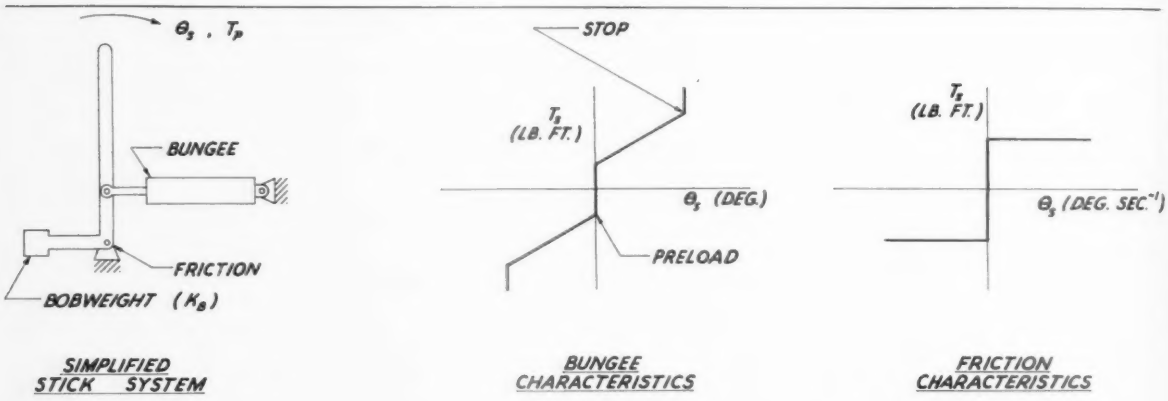
As the pilot exerts a force on the control column, the input, X_i, to the hydraulic servo moves an amount determined by the pilot applied force, F_p, and the dynamic and static impedance of the input system connecting the control column with the servo input. In like manner, the hydraulic servo then moves the controlled surface through an angle δ_e. The surface deflection then causes the airplane to undergo a normal acceleration, N_z, and pitching acceleration, $\ddot{\theta}$, which cause the bobweight to exert a force on the control column. To this basic system the stability augmenter shown by the accelerometer and equalizer has been included in Fig. 2. This device detects airplane normal acceleration, N_z, and by means of an extensible line causes the control surface to move through an angle in addition to that resulting from pilot input.

In a preliminary analysis linear characteristics of the system are assumed, and the stability and response are determined analytically. This requires analytical combination of the differential equations describing each of the subsystems involved. The differential equation relating hydraulic servo input X_1 to pilot force F_p applied at the control column, the differential equation governing the response of a hydraulic servo, and the three longitudinal equations of motion of the airplane are presented in Figs. 3a and 3b. The combination of these equations to determine the response of the complete airplane flight control system is a straightforward, though somewhat tedious, procedure. The procedure utilizes manipulations of complex variables and solution of the differential equations by Laplace transform techniques associated with Bode and Nyquist plots, root locust plots, etc. Its chief limitations are the difficulties in introducing nonlinearities present in practical systems and in rapidly determining the effect of parameter changes. The analog computer successfully overcomes these disadvantages. However, the analytical method can be used to advantage during early stages of the design when the system can be simplified and linearized. Some of the relative advantages of analytical and analog computer techniques will be evident in the following paragraphs.

* It is assumed here that the pilot flies primarily by force feel, provided that the control column displacements are conventional.

The Analog Computer

The introduction of nonlinear characteristics can be shown readily by reference to the control column system of Fig. 1 and the simplified stick system of Fig. 4. In Fig. 4 the net moment applied to the stick system is the difference between pilot moment T_p and bobweight



$$T_p - K_B n_B = I_s \ddot{\theta}_s + D_s \dot{\theta}_s + K_s \theta_s$$

$$T_p - K_B n_B = I_s s^2 \theta_s + D_s s \theta + K_s \theta_s$$

T_p = PILOT INPUT STICK TORQUE

T_s = STICK REACTION TORQUE

θ_s = STICK DEFLECTION

I_s = STICK SYSTEM MOMENT OF INERTIA

K_B = BOBWEIGHT CONSTANT

n_B = NORMAL ACCELERATION AT BOBWEIGHT

Fig. 4. Stick system characteristics.

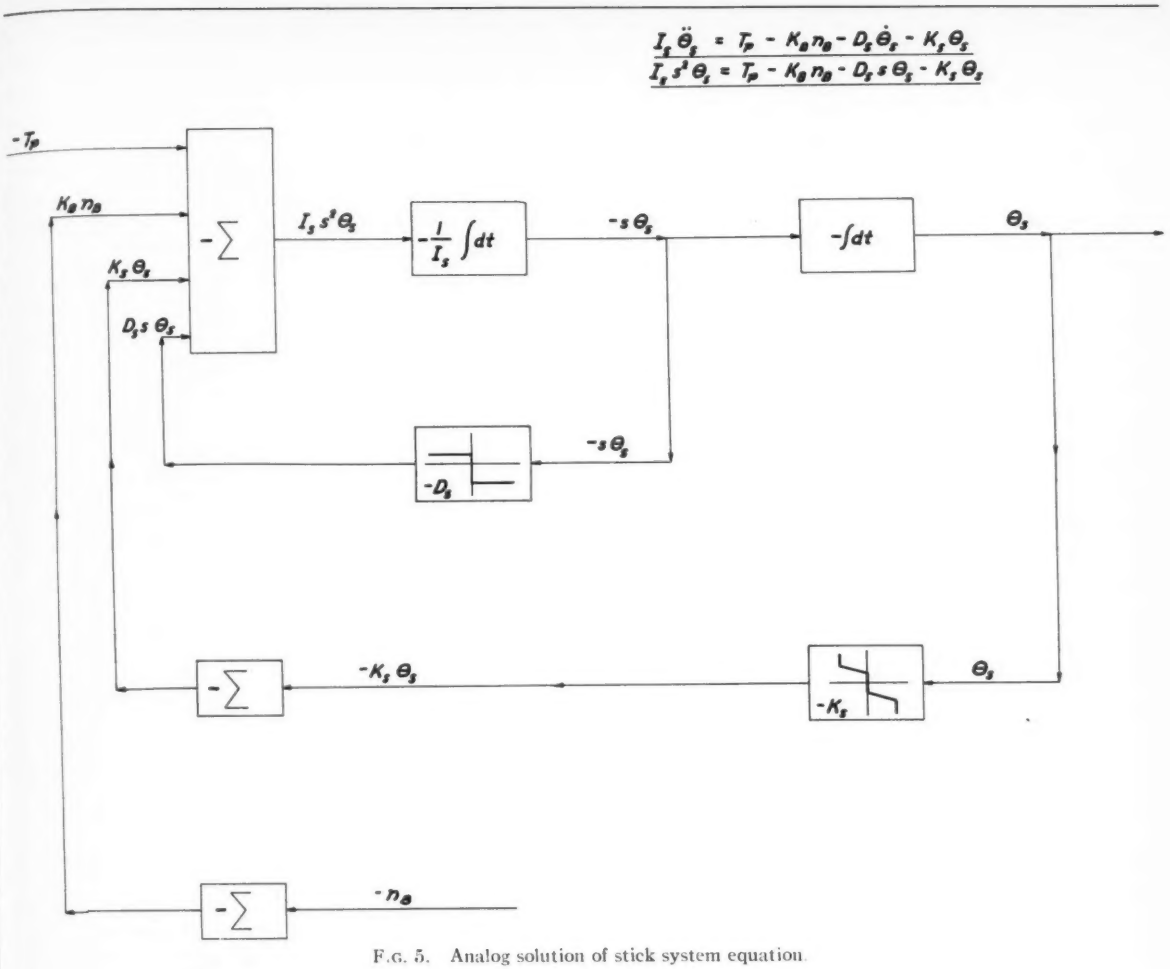


FIG. 5. Analog solution of stick system equation.

force $K_B N_B$, where N_B is the airplane normal acceleration at the bobweight location. The differential equation governing the simplified stick system is presented in Fig. 4. In this equation the operators D_s and K_s are not the usual damping and spring rate constants used with linear differential equations but are the operators described by the damping and spring rate plots of Fig 6. The damping plot represents friction, and the spring rate plot represents spring preload, spring rate, and effect of stops. Although this equation is difficult to solve analytically, it can be set up with ease on an analog computer.

The computer mechanization chart that solves the equation of Fig. 4 is given in Fig. 5. In this figure, operations such as integration addition and the introduction of nonlinear characteristics performed by the analog computer are shown. It can easily be seen by inspection that Fig. 7 is a block diagram of the equation of Fig. 4. To provide the correct analysis of Eq. (1) all that remains necessary is to produce electrical devices that represent the functions shown in Fig. 5. For the benefit of those who have not worked with computers, one method of obtaining the nonlinear friction characteristics will be described briefly. Other operations are carried on by similar circuits. The circuit for this

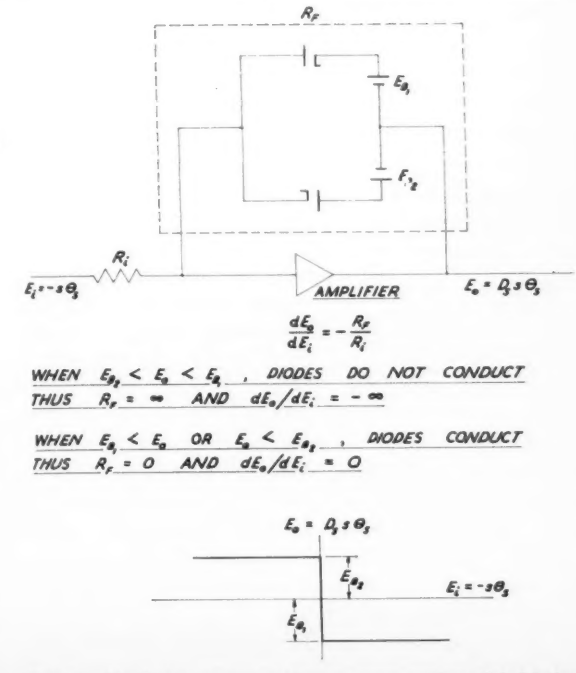


FIG. 6. Nonlinear computer element representing stick friction.

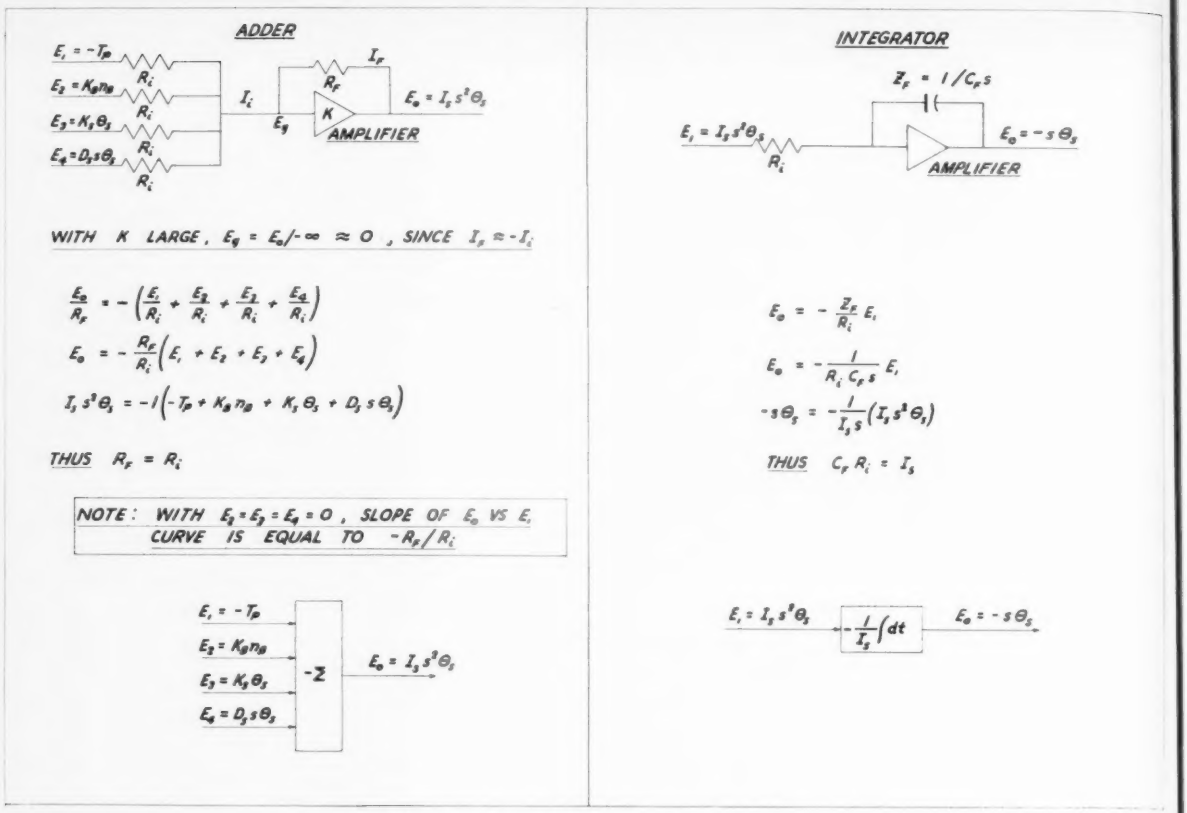

ADDER
AMPLIFIER
WITH K LARGE, $E_g = E_o/-\infty \approx 0$, SINCE $I_f \approx -I_i$
$\frac{E_o}{R_f} = -\left(\frac{E_1}{R_i} + \frac{E_2}{R_i} + \frac{E_3}{R_i} + \frac{E_4}{R_i}\right)$
$E_o = -\frac{R_f}{R_i}\left(E_1 + E_2 + E_3 + E_4\right)$
$I_s s^2\theta_s = -1\left(-T_p + K_\theta n_\theta + K_s\theta_s + D_s s\theta_s\right)$
THUS $R_f = R_i$
NOTE: WITH $E_2 = E_3 = E_4 = 0$, SLOPE OF E_o VS E_i CURVE IS EQUAL TO $-R_f/R_i$
$E_o = I_s s^2\theta_s$
INTEGRATOR
$Z_f = 1/C_f s$
AMPLIFIER
$E_o = -s\theta_s$
$E_o = -\frac{Z_f}{R_i}E_i$
$E_o = -\frac{1}{R_i C_f s}E_i$
$-s\theta_s = -\frac{1}{I_s s}(I_s s^2\theta_s)$
THUS $C_f R_i = I_s$
$\int dt$

FIG. 7. Adding and integrating circuits of the analog computer.

function is shown as Fig. 6 (description of nonlinear friction function device). The purpose of this circuit is to provide an output voltage, E_o, which is the function of input voltage, E_i, shown in the graph of Fig. 6. This is accomplished as follows: When $E_{B2} < E_o < E_{B1}$, the diodes of Fig. 6 do not conduct, and the circuit consists essentially of a single high-gain amplifier. Extremely small changes in E_i (because of the high gain) produce large changes in E_o. However, as E_o either increases so that $E_o > E_{B1}$, the lower diode of Fig. 6 conducts (no resistance), and the output voltage, E_o, has the value E_{B2} regardless of any further increase in E_i. The same effect is produced as E_i is reduced causing E_o to approach the value E_{B2}, at which time E_o must be equal to E_{B1}, no matter how small E_i becomes. Operation of the analog computer integrator and summer can be shown by the illustration of Fig. 7, which includes the simplified circuit diagrams and derivation of the analog equations.

If a similar procedure is followed for the entire flight control system the block diagram of Fig. 8 is obtained. When this block diagram is converted to an electrical analog circuit, it simulates the entire flight control system. All types of inputs such as step inputs, ramp functions, or sine waves can be applied to the system, and instruments can be provided to measure any of the airplane responses desired.

A photograph of such an experimental setup is presented as Fig. 9a. The analog computers are located on the right-hand side of the figure. The instrumentation consisting of a recording oscillograph and supporting voltmeter, etc., is shown on the left-hand side. Typical results obtained from an analog computer are given in Fig. 9b and represent data obtained with the stability augmentation system of Fig. 1. The objective of the test was to determine the desired location for the accelerometer to be used in the longitudinal stability augmenter. This accelerometer would, by means of an extensible length, provide a surface deflection δ_e proportional to n_z and rate of change of n_z with time, $\dot{n}_z$. It is clearly indicated by the oscillograph traces that the system is unstable with the accelerometer located at the center of gravity but is satisfactory when the accelerometer is located at a distance 1 ft. or more ahead of c.g. Fig. 10 represents the oscillograph traces observed when a dead band or threshold was introduced into the accelerometer such that no accelerometer voltage was produced until the change in acceleration exceeded 0.5 ft. per sec.^{2}. It would have been tedious work to predict the oscillation due to backlash which is evident in Fig. 10.

ANALOG COMPUTER AND FLYING TEST STAND

When a flight control system is produced, the characteristics of its components are always somewhat different from those predicted. In order to minimize these differences the actual flight control system components

are installed on a test stand as shown in Figs. 11 and 12. Fig. 11 is a view of the simulator from above and aft and shows clearly the rudder, the elevator, and one aileron. The control cables and hydraulic system are located below the catwalk and cannot be seen in the photograph. Fig. 12 is a downward view of the simulated cockpit showing the pilot's seat, the control stick, and some of the instrumentation. In addition to stick-free tests, other tests are conducted with the pilot sitting in the cockpit and "flying" the simulator by observing the instruments mounted on the instrument panel. In this manner, pilot comment can be used to some extent in the design of the control system prior to actual flight.

A block diagram of the experimental setup appears in Fig. 13. Here the pilot is shown operating a control system. The control surface deflections δ_a and δ_r are detected electrically and introduced to the analog computer, which simulates the airplane aerodynamic response and presents this information to the control system sensors. The sensors, in turn, cause the electronic circuits of the control system to operate the control surfaces by means of the hydraulic servos. Recorders are included to obtain data of the pertinent parameters. The outstanding limitation of a setup such as this consists of lack of realistic visual presentations to the pilot and lack of accelerations and orientations which the pilot would normally experience in the air.

An interesting example of such a simulator study is shown in Fig. 14. The results shown in this figure were obtained from a longitudinal control system similar to that of Fig. 1. With this system, the proper feel forces were applied to the control column by means of a force servo that obtained its inputs from the analog computer. The test consisted of the pilot pulling back on the control stick until a steady-state normal acceleration was obtained. The stick was then abruptly released, and the normal acceleration was recorded as a function of time. As is evident in Fig. 14, the response to this input was entirely different with a steady-state acceleration of $3g$'s than with $2g$'s. With each of these inputs the system itself was exactly the same. This is an example of a nonlinear effect that would not have been predicted by analytical methods.

Another important application of the flight simulator is the investigation of results of possible component failures. In this application a systematic program is conducted to effect various failures such as tube shorts, open circuits, noisy potentiometers, etc. Results are obtained with and without the pilot operating the controls. An example of the results obtained from such an investigation is given in Fig. 15 where the airplane response to two different tube failures occurring within

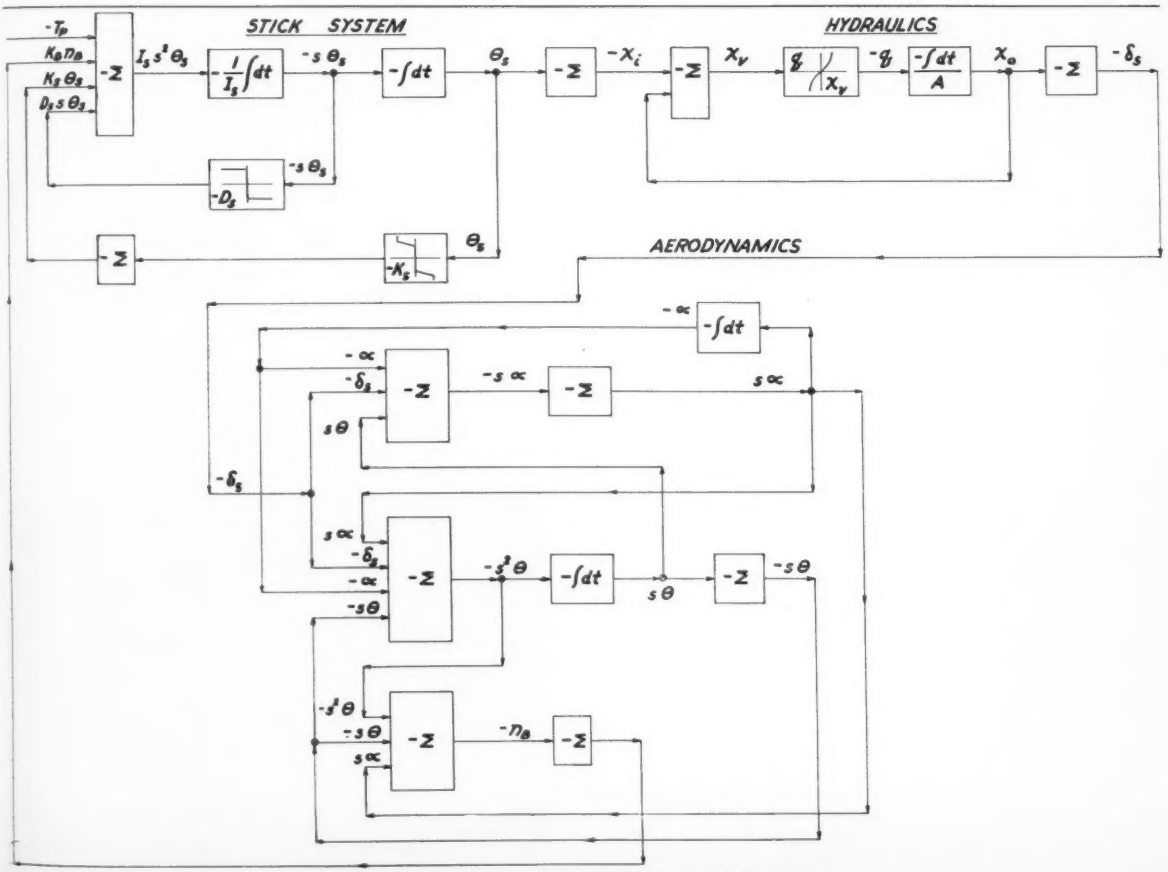


FIG. 8. Complete analog solution of longitudinal control.

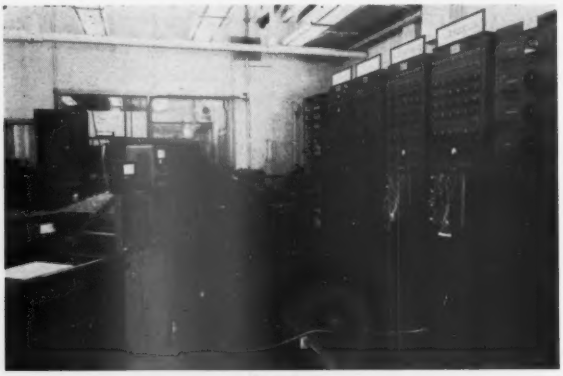


FIG. 9a.

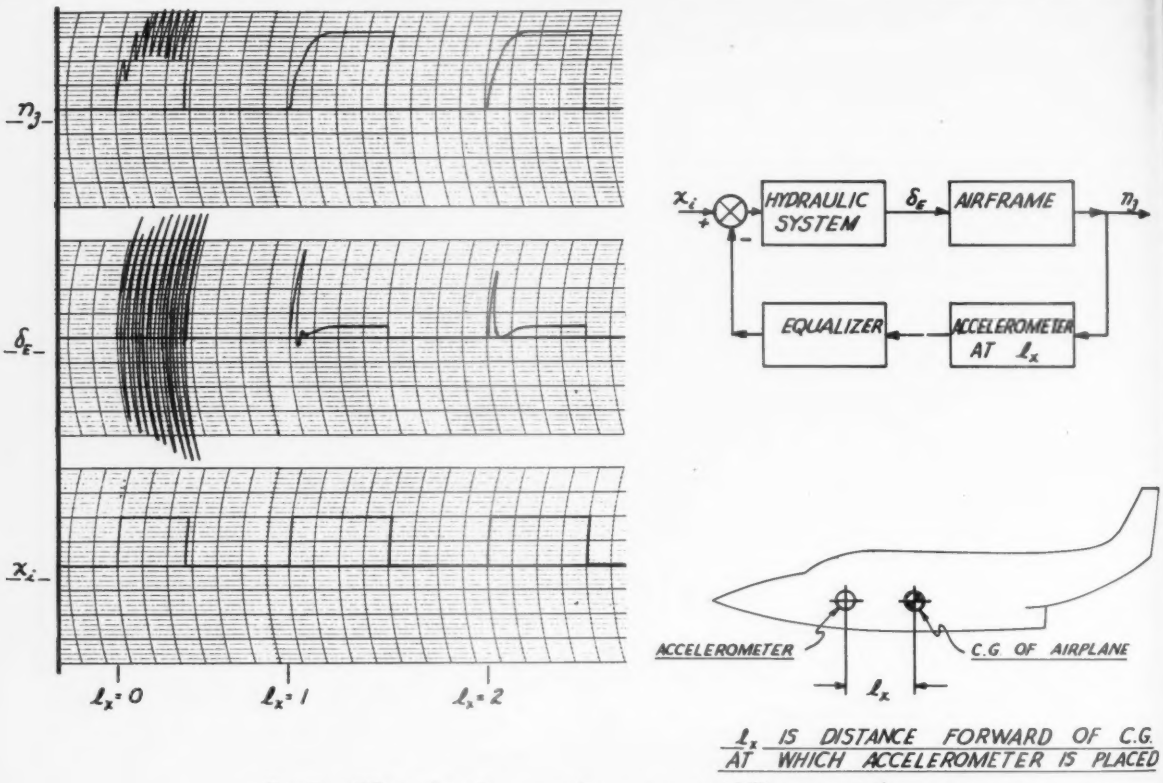


FIG. 9b. Effects of accelerometer placement upon stability augmentation.

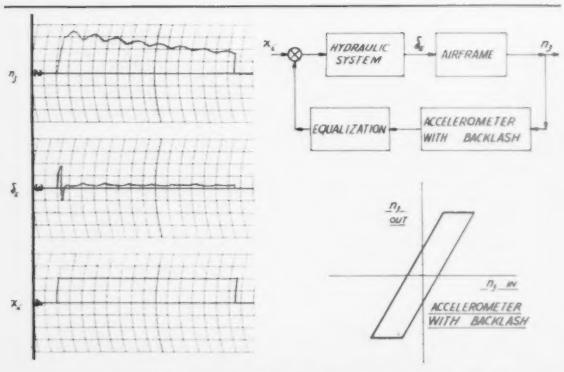


FIG. 10. Effects of backlash in sensor upon stability augmentation.

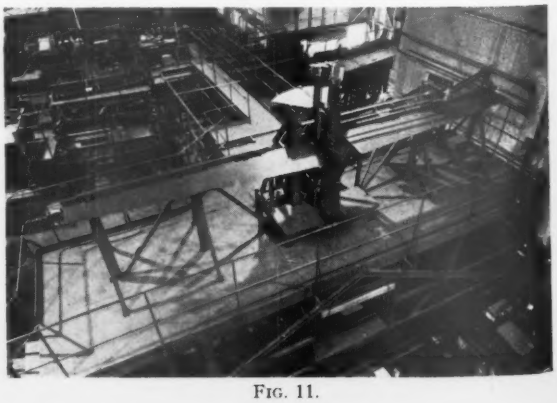


FIG. 11.

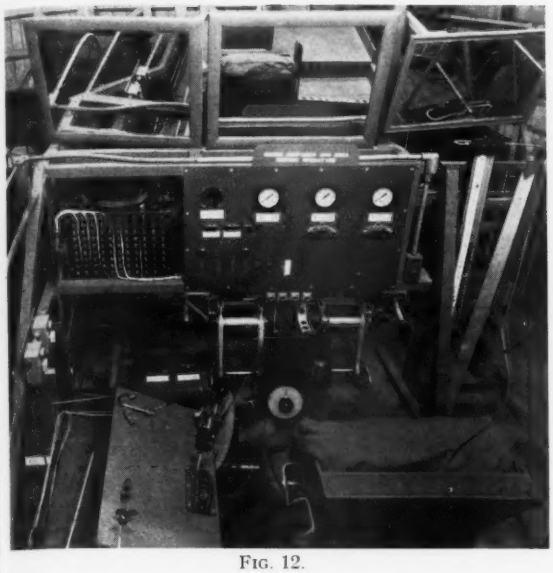


FIG. 12.

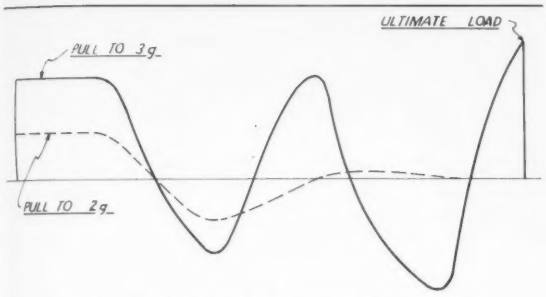


FIG. 14. Typical transient response characteristics.

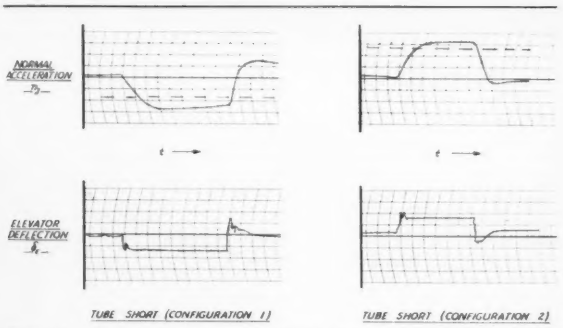
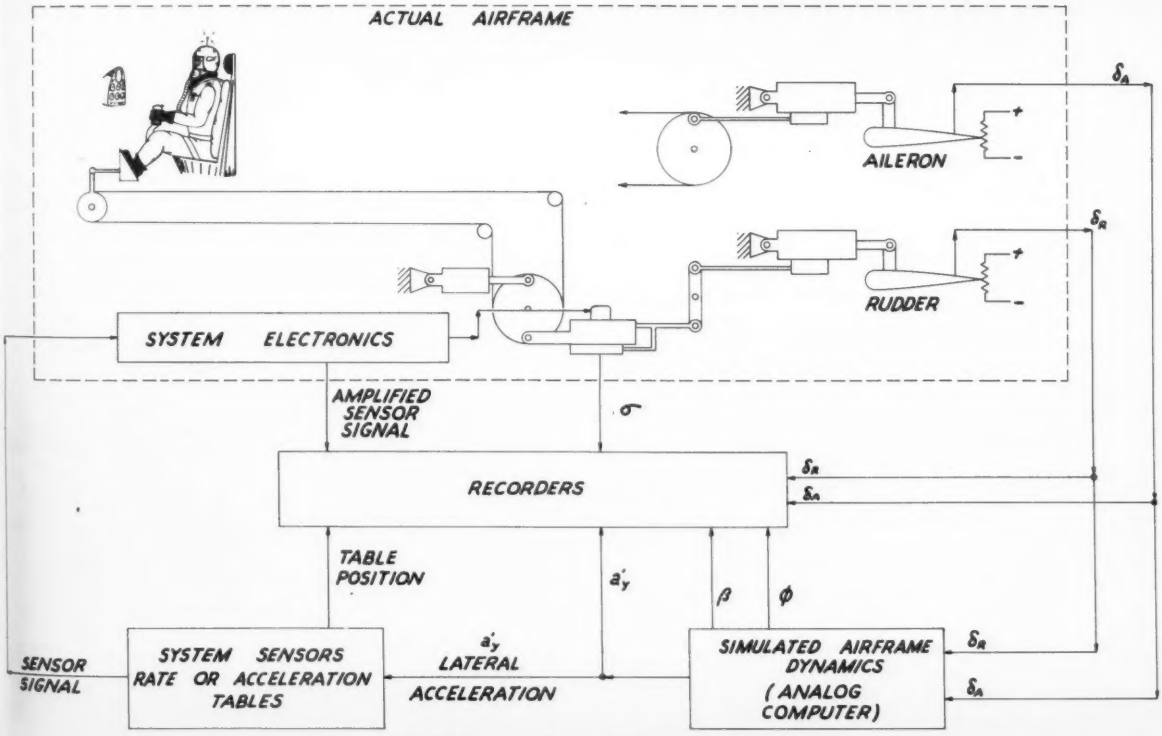


FIG. 15. Simulation of grid-cathode short in autopilot amplifier tube.

FIG. 16.



F.G. 13. Block diagram of ground check-out configuration.

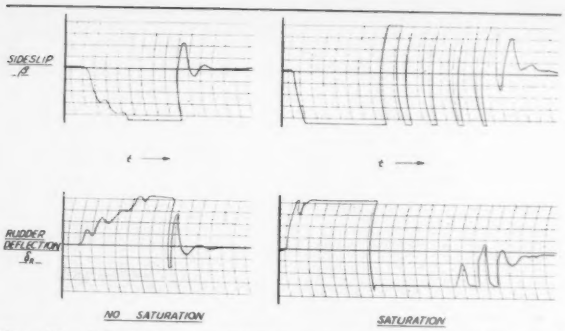


FIG. 17. Effect of system saturation due to extreme cross-control maneuver by pilot.

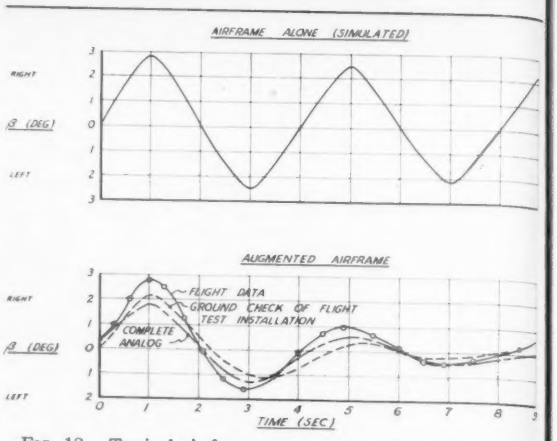


FIG. 18. Typical air-frame response to pulse rudder input.

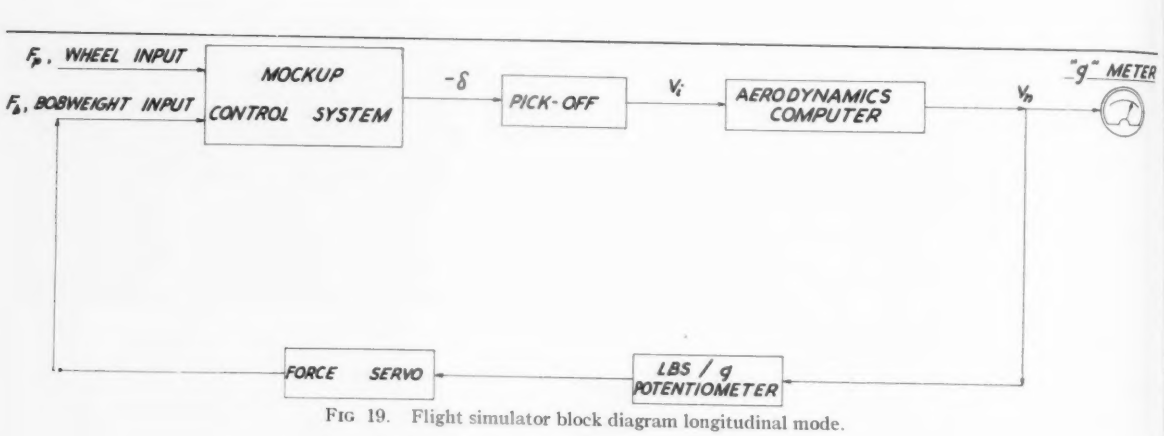


FIG 19. Flight simulator block diagram longitudinal mode.

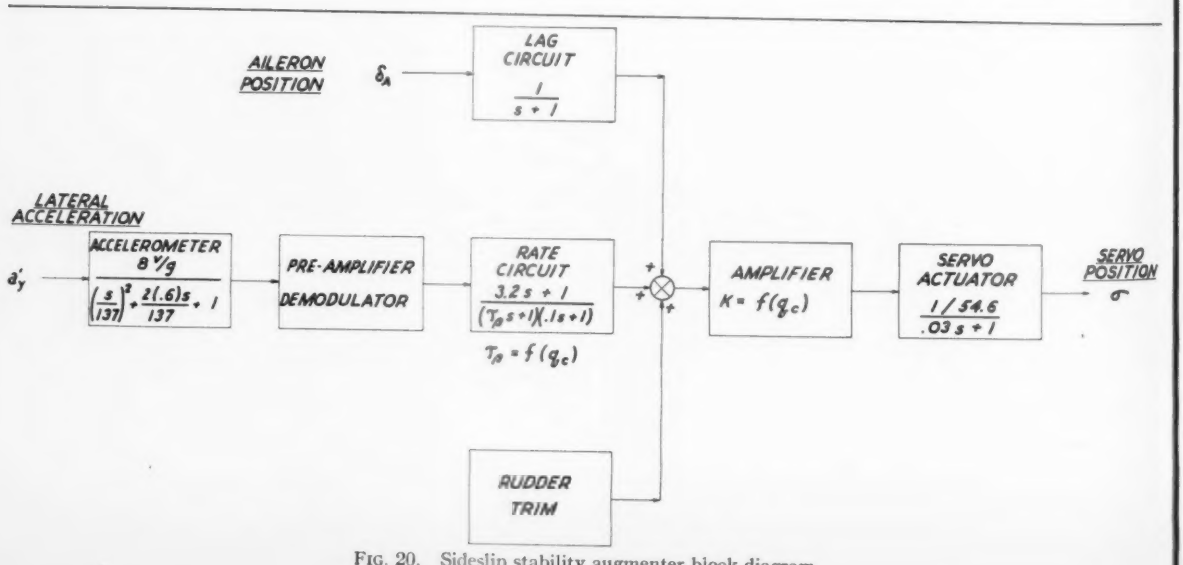


FIG. 20. Sideslip stability augmenter block diagram.

an autopilot is shown. In both cases the limit load factor of the airplane was exceeded, negatively in the one case and positively in the other. The pilot was not operating the control system in this test. Other tests have shown that pilot reaction to some failures actually result in a worse condition than if the pilot had not reacted at all. It is obvious that tests of this nature do not only save flight time but cannot be conducted in flight because of the danger involved.

Analog Computer with Airplane

This step in the procedure of developing a flight control system is similar to that conducted with the flight simulator, with the exception that the airplane itself is substituted for the test stand. Differences observed and changes made at this point are caused by installation in the airplane. A typical test setup is shown in Fig. 16. Starting from the right-hand side of this figure, the recording oscillograph, the analog computer, an oscilloscope, and a tilt table can be seen. The system under test is a sideslip stability augmenter that is used to maintain sideslip at zero. The basic sensor is a lateral accelerometer that detects lateral accelerations and after equalization moves the rudder to reduce the acceleration to zero. The accelerometer was mounted on the tilt table shown in Fig. 16 to avoid the necessity of analoging the accelerometer. Orientation of the tilt table is controlled by the analog computer so that at each instant the table angle is the same as airplane lateral acceleration as indicated by the analog computer. One of the results attained with this setup is shown in Fig. 17 where sideslip and rudder deflection are plotted as a function of time with sharp rudder deflections serving as system input. With large inputs it is clear from Fig. 17 that the system damping was unacceptably low. However, under normal operation—i.e., reasonably small rudder inputs—the system damped satisfactorily.

From a comparison of the results obtained by complete analog computer studies, by combined airplane ground tests, by analog computer representing the aerodynamic response, and actual flight data as shown in Fig. 18—along with the airplane sideslip characteristics obtained with stability augmentation, it is apparent that both the simulator and analog computer results agree closely with flight-test data. The figure also indicates that the stability augmenter considerably improves the airplane damping and sideslip.

Conclusion

After a discussion of this type, the question often arises as to the need for all of the steps described above. The answer to this is that simulation studies have two objectives: to obtain results as early as possible and to minimize errors by using as many actual unsimulated components and parameters as possible. It is a compromise between these two objectives which usually constitutes the number of steps outlined above. For example, it would not be practical to assume that the flight control system installed on an airplane would be identical with the analog of the system produced before the design was made. This necessitates the testing of the airplane installation itself. In like manner, it would not be feasible to design the system without analog computer studies and wait until the system were installed on an airplane before determining whether or not the system would perform satisfactorily.

The analog computer has become an almost irreplaceable tool in the design of airplane flight control systems during the last 10 years. It allows much of airplane "flight" testing to be conducted on the ground and enables the engineer to observe airplane responses much more directly than has heretofore been possible. The analog computer provides such quick results that extra care must be taken to avoid the pitfalls of random knob tuning and use of poor analogs caused by hasty setups. It must be constantly borne in mind that the analog computer can produce results only from the setup with which it is provided. Frequently, especially in this day of rapid advancement of the science of flight controls, the aerodynamicist, the flight controls engineer, the vibration engineer, or another engineer providing basic data that the analog computer needs, does not include or correctly evaluate all of the airplane parameters or degrees of freedom. When this happens, the computer obviously cannot produce results that agree with flight data. The solution of such a dilemma must come from re-evaluation of the parameters and subsequent revised mechanization of the analog computer. These discrepancies will always occur as long as airplane flight control systems are required to improve in performance or to control airplanes at higher speeds and altitudes.

Future improvements in analog computer application are needed mostly in the "flying" test stand phase. In this phase, the results of the simulator testing could be considerably improved by the use of a more realistic presentation to the pilot than is currently available. Possibly a moving-picture projection of clouds or other airplanes could be provided in the cockpit. Although seemingly impractical at present, the application of normal and lateral accelerations to the human pilot's body should considerably improve results and extend the usefulness of the analog computer.

The Flight Simulator Modification Problem

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THERE ARE presently in operation, throughout the world, about 145 pilot-crew flight training simulators representing some 24 different models of aircraft and an investment well over $100,000,000. Most of these simulators were built in the United States. Five different types are in air-line operation. Figs. 1 to 7 illustrate typical jet fighter, transport, and multi-engined bomber simulators. Our Air Force is by far the largest user of simulators for pilot and crew training, and all their new combat aircraft are being supported by flight simulators. Utilization of these machines varies among the Air Force, Navy, and air lines, and averages are reported from 170 to 300 hours per unit per month. The Air Force has announced that the hourly cost of operating cargo and transport-type flight simulators is $^1/_{10}$ that of operating the aircraft.† For bombers the ratio is about $^1/_{40}$. Even more startling relationships exist in other types. Reports from the Air Force indicate that the savings from a cargo simulator operating 4,800 hours per year are over $1,500,000. This means that they are offsetting their original cost in less than 1 year. Air Staff policy is that flight simulators improve quality, prevent accidents, minimize check-out time, and permit emergency procedure training not previously possible.‡

In 1954 there was a turning point in flight simulator planning and procurement. Previously, we were catching up with existing models of aircraft, and the simulators were utilized for (a) transitioning quantities of pilots from other types and (b) routine recurrent pilot-crew training for maintenance.

In the future, most simulators will be built and delivered well ahead of the first flight of the mother aircraft. This will give the simulator the additional utility of providing (1) initial qualification of test pilot personnel on the new and unflown airplane, (2) means for investigating the human factors in man-machine relationships, and (3) alleviation of major "bugs" in the new design.

As further experience with these simulators is acquired, more applications will develop. For example, if a simulator were phased into the aircraft program at a sufficiently early date, it could also provide means for evaluating design parameters of drawing-board aircraft in terms of pilot acceptance.

Because simulators are expensive, ranging from several hundred thousand dollars for production units to well over a million dollars for large multiengined prototypes, it is essential that they be employed as effectively and for as long a life as possible. Maximum training is derived from simulators when they fully reproduce operational situations. Hence they should, as nearly as possible, represent the whole task. A simulator, if properly designed and used, assures not only the balance but also the presence of all skills. Care should be exercised to avoid developing isolated skills as they may have unpredicted transfer effects. This is one limitation of part-task trainers. It is also important not to omit the learning of other skills that, because of their absence, may produce dangerous transfer. Whole-task simulators offer the completeness and high fidelity in performance required for correction of negative skills acquired elsewhere and provide for development of crews with integrated learning relevant to a specific model of airplane.

When a crew has reached the desired proficiency in handling the aircraft under all conditions, most of the operations have become habitual. To promote good habits and develop judgment an instructor's station is provided for controlling and monitoring the flight (Fig. 8). Over 100 troubles can be introduced at a console to simulate specific failures or progressively compound irregularities into emergency situations (Fig. 9). Because a simulator can operate beyond the safe limits of the actual aircraft, it permits the learning of more emergency task skills than the airplane itself. United Air Lines, Inc., which uses four simulators, reports that in an 8-hour simulator course their crews are receiving more

Presented at the Electronic Aids to the Aircraft Industry Session, Twenty-Third Annual Meeting, IAS, New York, January 24–27, 1955.

* Chief Engineer, Electronics Division.

† Minutes of USAF World Wide Flight Simulator Symposium, p. 158.

‡ *Ibid.*, p. 5.

experience in handling malfunctions of the aircraft than they obtain in 15 to 20 years of line flying.

To the extent that we build simulators while the aircraft is still on the drawing board or during X-model development, major modifications will occur during the construction and life of the simulator. *The expedient handling of these changes is the most important current simulator problem.* There are two phases of this problem: (1) to determine which aircraft changes should be incorporated in the simulator, and (2) to incorporate the necessary revisions with the least cost and loss of simulator operating time.

The decision whether or not to incorporate an aircraft change in the simulator must be based on training value since our concern is with simulating task requirements and not equipment—unless the simulator is designed to aid aircraft development also. The extent to which a modification is required for this task simulation or for adequate student motivation varies in each instance. Accordingly, there can be no absolute criteria for evaluating changes. However, the following may serve as a guide to show changes that, if significant, are usually desirable in the simulator:

(1) Performance—(a) Changes in basic stability derivatives or power. (b) Changes in rate, magnitude, or nature of any basic system.

(2) Configuration (Cockpit)—(a) Location or appearance of instruments, lights, switches, or controls.

(3) Procedure—(a) Changes in aircraft equipment resulting in revisions to operating sequences, direction, or magnitude whether normal or emergency.

It is entirely feasible to design and build pilot-crew flight simulators concurrently with new aircraft, and it is also practical to keep them current with respect to aircraft revisions affecting training. However, to do so will require adoption of the following policies:

(1) Good liaison between the aircraft and simulator manufacturers for rapid and adequate provision of change notices, data, and parts.

(2) Provision of funds and delegation of authority to simulator manufacturer to use his own judgment regarding inclusion of any scheduled aircraft modification (subject to customer stop-order control).

(3) Continued development and standardization by the manufacturer of simulator components and systems which are universally applicable to all types of aircraft and will easily accommodate aircraft changes.

(4) Maintenance of qualified and adequately equipped factory and field personnel to incorporate changes as required.

In considering the above, the problems with respect to policy No. 3 may be the least obvious and therefore warrant a brief review. One of the foremost considerations of any manufacturer is a constant reduction in cost consistent with quality and scope of product requirements. The simulator manufacturer adds the somewhat unusual objective of easy conversion from one model or set of characteristics to another. Both objectives are accomplished by designs that have universality of application and can therefore be standardized. Accordingly, Curtiss-Wright several years ago engaged in an intensive program for standardization of flight simulator components and assemblies. All likely configurations of aircraft were considered. Design parameters for existing and probable engines and air frames were cataloged and their ranges listed together with expectable variations. This formed the basis of versatile analog circuitry for flight and engine simulation. In addition, many components were standardized as shown in the following tabulation:

STANDARDIZED EQUIPMENT ITEMS

Radio aids
Recording apparatus
Regulated power supply
Supplementary power supplies
Main distributing frame
Control loading mechanisms and amplifiers
Interconnecting cables and rack structures
Instructor's housing (modular)
Various instrumentation
Flight computer
Engine computer
Computing amplifiers
All servos, gear boxes, and potentiometer components
Air conditioning

In the aggregate, the above standardized assemblies represent about one-half of the manufacturing cost of the simulator. Since they comprise the greatest portion of the simulator, it is obvious that continued cost reduction efforts should apply with particular emphasis on the remaining apparatus not listed.

An objective in the design of each standardized unit and its associated mounting accessories was that it could be replaced with improved equipment with a minimum effort.

The success of this program is indicated by use of the resulting standardized items in the design of the twelve different simulator models below:

C-119C	C-119G
C-124A	C-124C
B-36	C-121
DC-6B	C-118
DC-7C	C-130
CV-340	C-131

In discussing simulators and their components, the flight and engine computers have by far the most popular appeal.

Both analog and digital computers have individually unique characteristics that are desirable for whole-task flight simulator use. However, only the analog system has been successfully employed to date. This is because the analog has lent itself better to real-time integration, which is the fundamental computation process in flight simulators. Moreover, it has been better adapted for operation from and into the pilots' controls and the flight instruments that are themselves characteristically analog devices. However, recent improvements in speed and logic as well as in analog-digital transducers are making the digital computer somewhat

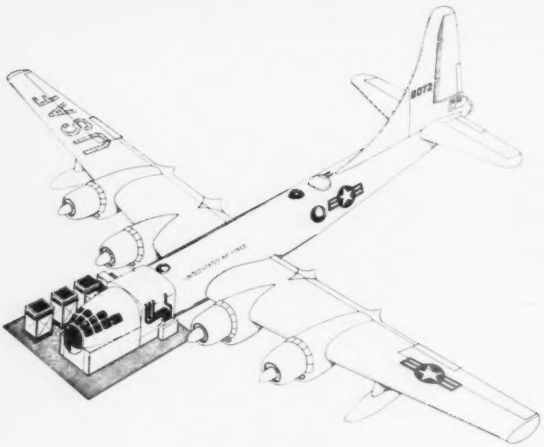

FIG. 1. B-50.

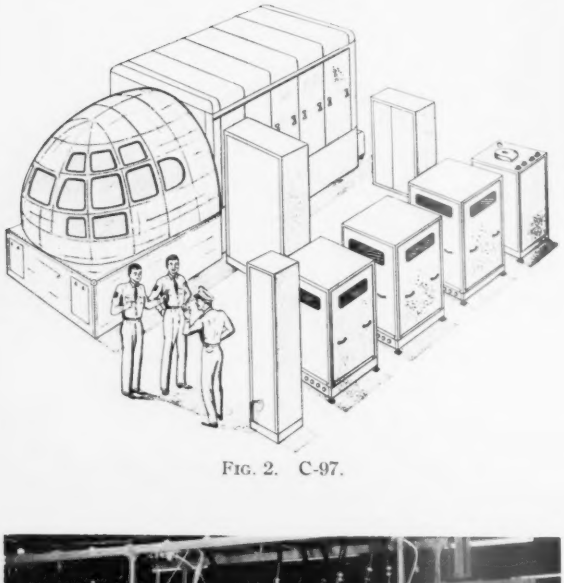

FIG. 2. C-97.

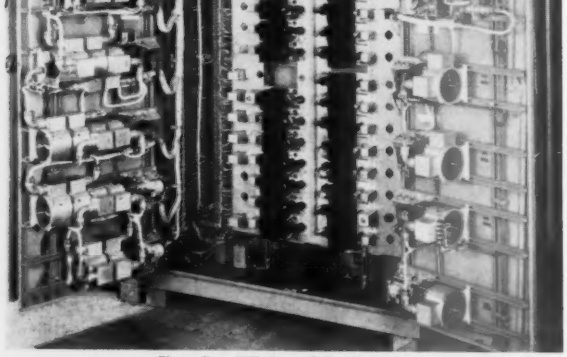

FIG. 5. Flight cabinet open.

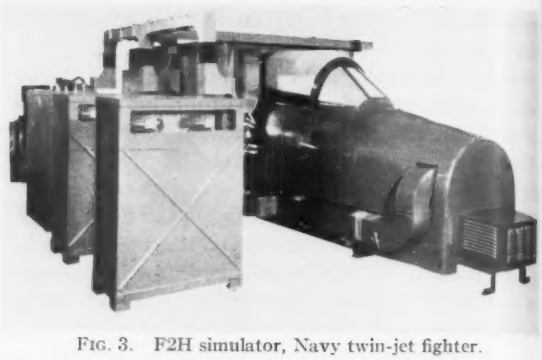

FIG. 3. F2H simulator, Navy twin-jet fighter.

FIG. 4. DC-6.

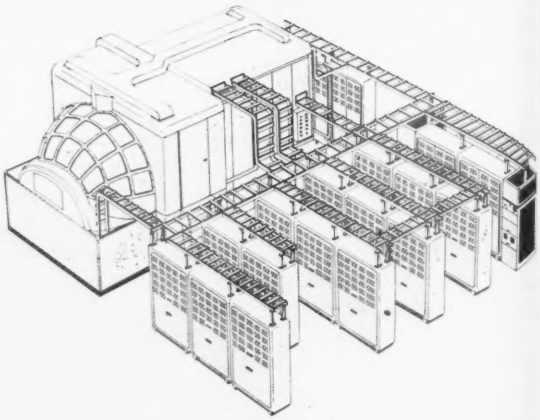

FIG. 6. B-36.

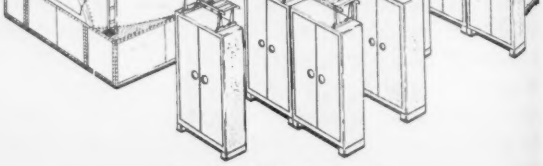

FIG. 7. C-124 simulator.

more of a contender than in the past. There also have been numerous advances in means for increasing storage capacity. This is essential in whole-task flight simulator application because of the many parameters employed and the multiplicity of operations performed on them. Digital computers afford good accommodation to aircraft performance modifications through programing. In addition, they have the inherent attributes of high accuracy and repeatability. Therefore, as the capacity, real-time performance, and cost of digital machines (and their adaption accessories) become more competitive with the analog, they could find application in flight simulators. It is estimated that they may not fully compete with the analog for another 5 years or more.

With the present state of the art, analog computers afford superior simulation of aircraft performance, and, when developed from highly versatile, standardized units as described above, they provide satisfactory flexibility for handling model and performance changes. Their design has become so efficient that they represent less than 25 per cent of the manufacturing cost of a pilot-crew flight simulator.

Analog computers may be based on d.c. or a.c. carrier, or combinations of both. If a.c. is employed, the choice of frequency is conveniently that of the power line—or 400 cycles per sec. A.C. systems are simpler and more reliable than d.c. as they require fewer plate supplies, have much less contact trouble, possess more inherent component stability, and contain fewer circuit elements, particularly when the variables are nonlinear. D.C. computers are preferable when calculations require differentiation, step-function or other high-speed transient analysis, special initial or boundary conditions, and graphic display of the solution on an oscilloscope or chart. These are usual requirements in research work and have led to the development and extensive laboratory use of such general purpose d.c. analog equipments as the REAC, GEDA, Electronic Associates, and others. However, none of the above features of d.c. superiority are criteria for pilot-crew whole-task flight simulators. Here the requirements are continuous integration, provision of a hundred or more nonlinear function generators, moderate (1 per cent) accuracy, medium-frequency response (several cycles per sec. around a loop), shaft actuation of output indicators, and a high order of reliability.

Operational flight simulator computations may be regarded as depicting (a) static (constant acceleration) behavior and (b) dynamic (transient) behavior. A.C. 60-cycle computers have been thoroughly satisfactory for matching static characteristic performance data. They yield results well within the variations found among production aircraft. However, they have not heretofore matched the dynamic data as well because of integration dead-zones and somewhat inadequate servo response. Better frequency characteristics can be obtained more easily with 400-cycle operation than with 60 cycles per sec., but the long cabling of these

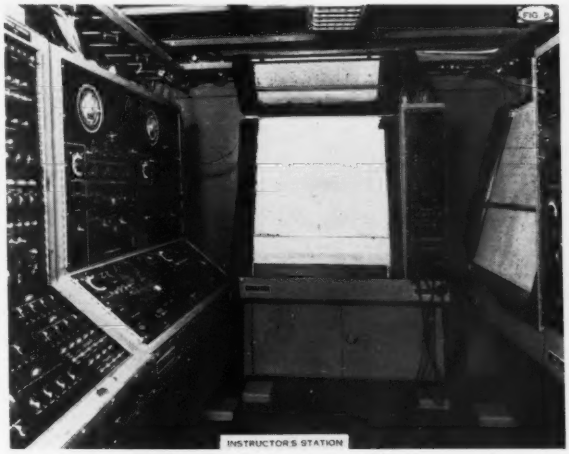

FIG. 8. Instructor's station.

simulators greatly increases cross talk, noise, and phase-shift, which impairs accuracy and further impairs integration range. Seeking in turn to alleviate these limitations, some designers have combined d.c. integration apparatus with 400-cycle servo-driven multipliers and function generators. These complications are unnecessary and can be avoided by more careful design of the 60-cycle servo components.

A recently developed high-response 60-cycle servo with excellent dead-zone reduction is shown in Fig. 11. In the upper rear of this picture is a set of contoured potentiometers. They are the function generators

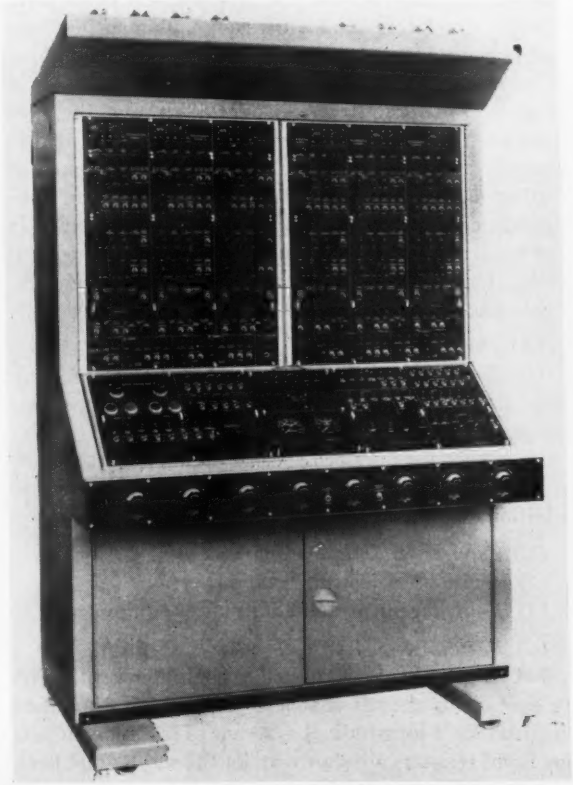

FIG. 9. Trouble console front.

that match the characteristics of a particular aircraft. These potentiometers assemble into the motor-driven servo unit shown at the center of the figure. In the immediate foreground is the amplifier that controls the motor and, just to the rear, is its low-frequency gain boosting network. This, in combination with good gearing, effectively overcomes dead-zones. The amplifier has adequate margin to avoid nonlinearities due to saturation, under the severest flight maneuvers. The frequency response of this servo is such that when used in combination with others in a multiservo-loop system, the capabilities are well in excess of the requirements to simulate any forthcoming airplane. As illustration, the system matches the frequency and damping of the short-period and phugoid oscillation of a high-speed airplane to approximately 2 per cent. A typical flight indicator can be seen at the left. This operates from the synchro-transmitter on the servo unit, which, in turn, moves in linear relationship to the computing potentiometers.

In designing computers for flight simulators, the end objective should not be forgotten. If this is primarily pilot training, computer fidelity should equal but need not exceed the match between production aircraft. It is much better, from a pilot-training viewpoint, to build a computer that will remain at its initial tolerance month after month with relatively little maintenance than it is to build a more complicated machine that, because of maintenance difficulties, deteriorates to a lower level. The 60-cycle computer has proved exceptionally reliable and, when properly designed, gives good repeatability in manufacture and throughout its life in the field. Air-line simulators employing such equipment are now averaging less than 1 per cent loss of scheduled time due to maintenance. A 60-cycle per sec. analog simulator in service with Pan American World Airways, Inc., has completed over 20,000 hours of training time at La-Guardia and is now re-installed at San Francisco for further daily operation. This machine has seen continued periods of use averaging 16 hours per day. It has been modified on various occasions, including propeller changes, to keep it current with the air vehicles.

Modifications to simulators may be classified as—

(*A*) *Performance Changes* (*Computer*):

(1) Change in performance characteristics involving only a change in the functions relating the same variables.

(2) A change in performance involving new variables.

(3) Inclusion of entirely new functions representing additional equipments.

(*B*) *Changes in Cockpit Configuration:*

(1) Revisions in instrumentation.

(2) Re-arrangement and additions of equipment.

(*C*) *Basic Design Improvements.*

Let us examine how an analog computer is modified to encompass aircraft changes. Fig. 10 is a simplified diagram for a longitudinal system. The proportionating input resistors are shown at R; the servo-amplifiers, potentiometers, and other components are similar to those of Fig. 11. Each functional potentiometer generates one of the terms in the respective equations.

If the change to the aircraft performance affects only the *slope* of a function, as shown by the dotted line of Fig. 12, this can be embodied in the analog computer merely by altering the value of the corresponding proportionating resistor. This resistor could in fact be made a variable rheostat as shown. The cost of such a change is largely the analysis time involved.

A more likely change is where the aircraft modification alters the shape of the function, as shown in Fig. 13. This is incorporated in a simulator by changing the contour of the potentiometer representing each affected function. Usually a change is also required in the value of the associated proportionating resistors. If there is a change in the intercept, an additional biasing resistor (input) can be added (Fig. 14). If dynamic characteristics are affected, as is frequently the case in an engine modification, a change in ratio of the servo gearing may be involved. Many different gear ratios have been standardized.

A type of modification to the aircraft which may appear innocent but is quite troublesome in the simulator is the substitution of one instrument for another with different scale expansion. Fig. 15 illustrates the effect. The change in scale of these wing flap indicators requires reshaping all of the potentiometers to compensate for the angular disparities and changing the synchro-transmitter gear ratio.

More serious than the foregoing modifications are the effects of a change in equipment which adds variables. Consider, as an example, the addition of a manual spark advance control for the engines. Fig. 16 shows the original basic circuit for the engine in solid lines. The dotted lines are additional apparatus necessary for inclusion of the manual spark control. Since the wires represented by the dotted lines run between computer cabinets, the trouble console, switches in the cockpit, and several distribution points, it is obvious that many wiring diagrams, chassis drawings, terminal designations, and apparatus drawings are involved.

It has been our experience that the average airplane modification affects about one-half of the function generators in the computers. Small changes usually can be individually included in a prototype simulator while it is in design and construction without delaying delivery. Larger changes, however, are more advantageously introduced in blocks. To avoid delivery delays, a freeze date for all changes becomes essential when the later stages of construction are reached. Procurement lead time is an important factor in establishing this freeze date. Availability of performance data is another most important factor.

One of the major items of costs in any modification program is the analysis of the aircraft and engine data. Flight simulator computers are designed according to the basic aerodynamic coefficients, derived from wind-tunnel data. On the other hand, subsequent flight-

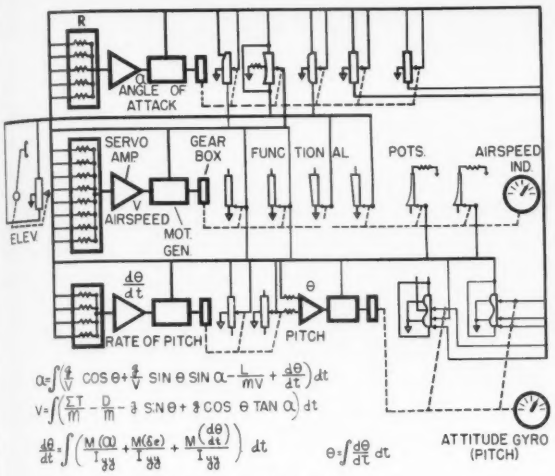

FIG. 10. Longitudinal system.

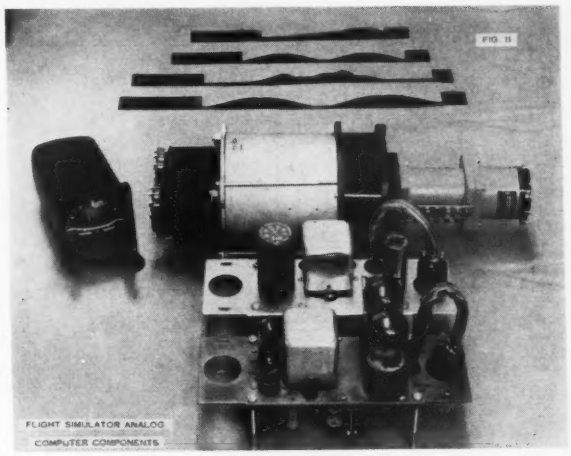

FIG. 11. Flight simulator analog computer components.

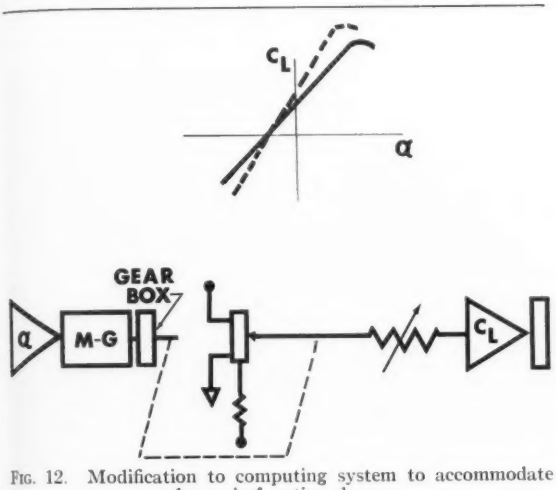

FIG. 12. Modification to computing system to accommodate change in function slope.

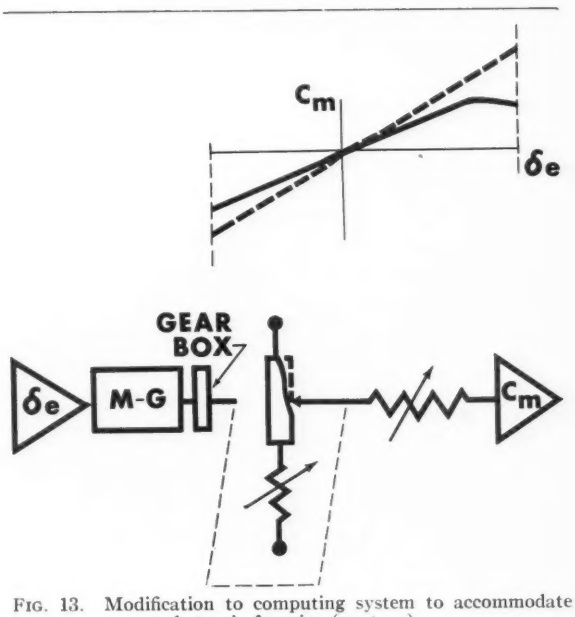

FIG. 13. Modification to computing system to accommodate change in function (contour).

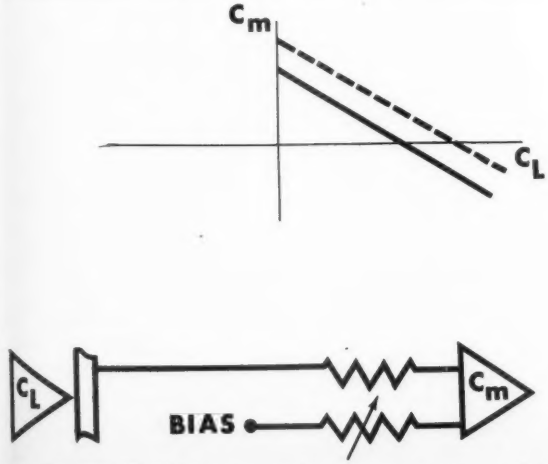

FIG. 14. Modification to computing system to accommodate change in function intercept.

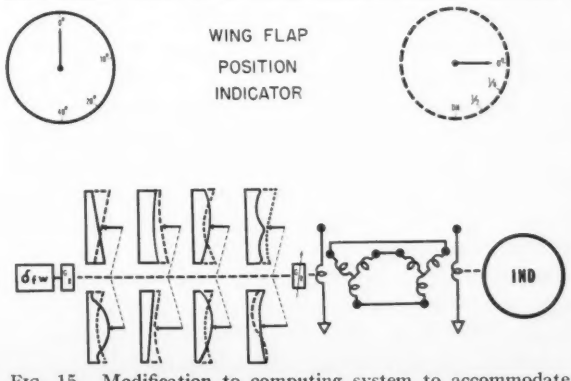

FIG. 15. Modification to computing system to accommodate change of cockpit indicator.

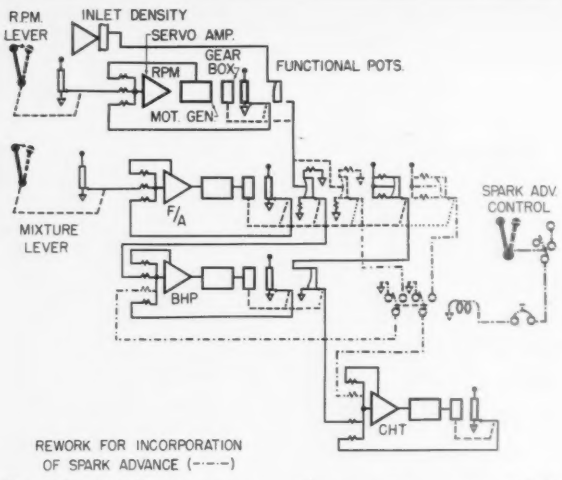

FIG. 16. Modification to computing system to accommodate additional functions.

test data, forming the criteria for simulator modification, are given in terms of directly measurable aircraft quantities such as force and deflection of the elevator and stick vs. air speed at various altitudes and power. Since many of the functions in a simulator must be computed to better than 1 per cent—e.g., speed-power at all configurations and altitudes—it cannot be assumed, *a priori*, that various parameters have not been affected. Verification requires the quite tedious transformation of flight data to the basic aerodynamic design parameters. Difficulties in this work are often introduced by incompleteness of data. Frequently the airplane manufacturer does not explore certain performance characteristics. For instance, in an engine modification, detailed ground run-up information is usually lacking because the airplane manufacturer was not interested unless an overheat or some other unsatisfactory condition prevailed. The form in which data is received is highly important. Often it is supplied as faired curves that, when consolidated and extrapolated to obtain intercept parameters, show distinct inconsistencies. Hence the simulator manufacturer usually prefers receipt of the test points themselves with only the test corrections applied. If the data are in error or inconsistent and scatter well beyond the tolerances acceptable for the simulator, our problem is nearly insolvable.

There is perhaps less need to discuss in detail the effect of *Cockpit Configuration Changes* because everyone concerned with aircraft can quite readily envision the work that any mechanical re-arrangement would present in the simulator. It may be simpler or more difficult to alter the simulator than the airplane. As illustration, if a simulated instrument has rear-of-panel dimensions larger than the corresponding aircraft instrument, troublesome interferences may develop in connection with certain relocation changes. Also, many wiring changes can occur as a result of instrument movement or substitution.

An example of a four-engined transport cockpit change now in work at our plant is modification of a C-97A simulator to C-97G configuration and performance. The respective flight engineer's stations are shown in Fig. 17. This change is essential to avoid negative transfer in training. Manual spark advance controls now occupy the location of the cowl flap and intercooler flap switches which have been moved from the forward flight engineer's panel to the side panel. Numerous instrument revisions have been made, including a change from dual 3-in. M.A.P. and r.p.m. instruments to individual 2-in. instruments. The fuel control arrangement is different, and electrical system controls have been moved. A number of similar changes will be evident on close inspection.

Basic Design Improvements are the last category of changes to be considered. These are usually infrequent and less troublesome than either performance or cockpit modifications. In general, revisions to incorporate basic design improvements arise through the availability of better apparatus and are made to improve maintenance and not pilot training. They are usually accomplished at overhaul or some other convenient time.

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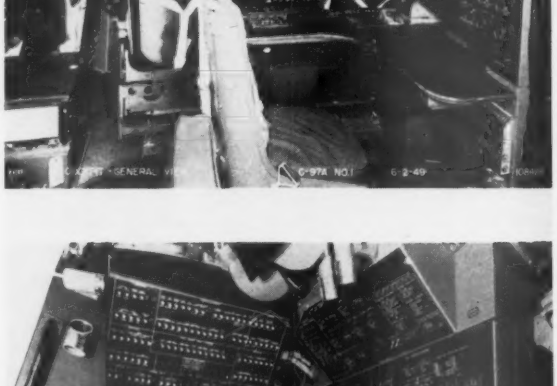

FIG. 17. Change in cockpit configuration: Upper view is C-97A; lower view is C-97G.

What Can Electronic Simulators Do for the Missile Designer?

FLOYD E. NIXON*
The Glenn L. Martin Company

WHAT CAN electronic simulators do for the missile designer? This is not a difficult question to answer; nor is it an easy one. The difficulty of answering the question is reduced if it is limited to a specific aspect. For example, you often hear that a certain computer is capable of 10,000 additions and subtractions per sec. or that another computer can solve 18 simultaneous differential equations. Hearing this, the average person replies with a polite "How nice!" But a supervisor or chief engineer replies with a challenging "So what?"

Probably all answers to the question "What can electronic simulators do for the missle designer?" fall into two major classifications. The first is that electronic simulators stimulate creative thinking, and the second is that they perform routine computations.

In the aircraft industry, it is difficult to justify the purchase or rental of an electronic computer on the basis that it can do as much work as 1,000 mathematicians at the cost of 10 mathematicians. Your chief engineer's viewpoint is that you do not have 1,000 mathematicians; therefore, why is such a computer needed? (This is not true in businesses that require large bookkeeping or inventory control staffs. There, routine computations can be done quicker, more accurately, and more efficiently with electronic computers.) However, I know of no engineering staff that has ever been reduced by the addition of electronic computers. Usually just the opposite occurs; the engineering costs are increased by the addition of the computer, and the engineering staff is appreciably increased, often by a factor of two or three. Accordingly, it is felt that the only justification for electronic computers lies in what they can do to stimulate creative thinking. Some examples will be discussed later.

These remarks should not be interpreted to mean that missile production costs are increased because electronic simulators are used; even the missile engineering costs are not increased. The first statement is the more evident, because by determining designs that are not feasible, the proverbial "stitch in time saves nine" applies, and misdirected missile production costs are reduced. Missile engineering costs are affected in a different manner. You no longer build the same types you did 10 years ago. Partially, this is because electronic simulators have helped you explore designs, speeds, and capabilities which would have required sizably larger engineering staffs if the same progress rate were maintained.

In order to discuss specific problems where an electronic simulator can aid design, it is necessary to refer to typical examples—for instance, the design of an air-to-air missile. Fig. 1 shows some of the design factors involved. First, the missile designer must decide on a type of navigation which adequately meets his design requirements. Design requirements are such things as cost, size, range, weight, and target capabilities. Several navigation methods are possible, and some are represented by the blocks in Fig. 1 entitled pursuit course, constant bearing, proportional navigation, and command control.

A pursuit course is one in which the missile always points toward the target. A constant bearing course is one in which a detecting element—for instance, a missile-contained radar—always points in the same direction in space. If the target moves, this is detected, and the missile moves until the pointing direction of the detecting element indicates that collision with the target will take place. This enables the missile to "lead" the target and predict the collision point. A proportional navigation course is one where the detecting element always tracks the target. If the detecting element must move to continue tracking, it indicates that the missile does not have the proper lead for collision. Therefore, the missile is turned an amount proportional to the detecting element's turning. Command control consists of an operator controlling the missile flight path to effect collision.

Each of these navigation methods can be studied on electronic simulators. This is done by expressing the

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* Chief of Simulation.

FIG. 1. Design factors of an air-to-air missile.

navigation method by mathematical equations and including in those equations additional effects that are important. For example, an air frame requires a certain finite amount of time to respond to a turn command. Realistic air-frame time lags must be included in the navigation studies. This does not mean that it is necessary to include a typical set of air-frame equations that include realistic force and moment coefficients. At this early design study stage, just the opposite is desired. We can assume that the missile air frame has certain response times and certain damping ratios and we can study the effect of varying these factors over wide ranges. Such a study might show that, as regards a certain navigation method, there is little difference between the hit probability if the missile air frame responds in 5 sec. or in 15 sec. This is extremely useful to the air-frame designer.

Similarly, a general study of navigation methods will show the requirements of other vital factors. In order to come within a tolerable miss distance, simulator studies may show that the missile maneuverability needs to be—for example—3*g*. This is vital information for the structures designer. Certain tactical situations may demand more than 3*g*—for example, they may demand 10*g* for a zero miss distance. But if the missile maneuvering capability is only 3*g*, the miss distance still may be adequately small. This is vital information for the designer of a *g*-limiting system. Thus if 3*g* is adequate, 10*g* may yet be required because of gusts or certain trajectory cases; an electronic or other method that limits the missile maneuverability should be incorporated if this reduces the cost structurally or otherwise.

These same generalized studies can zero in on the effect of practically every factor that affects missile performance. Noise of a type that is typically encountered can be injected at any point in the system. The launch point with respect to effect of the target approach aspect and range can be determined.

A typical special problem that arises is concerned with the stabilization of a missile-contained, target-tracking radar antenna. Suppose the missile were subjected to a gust that moved the air frame up 5°; the antenna would also move unless it were stabilized by a device such as a gyro which would move the antenna 5° down, thus keeping the antenna pointed in the same space direction. Studies are conducted to determine the effect on the navigating system with and without such stabilization. Let us take the problem just a little further. Suppose the antenna is stabilized so that it continues to point in the proper space direction. Now, however, it is viewing the target through a different portion of its radome, and it is entirely possible that this new portion refracts (or bends) the radar waves in a different manner than the preceding portion did. These studies are also important and can be accurately simulated on electronic computers.

Actually, studies such as have been mentioned should be classified as being more in the category of routine computations than as stimulating creative thinking. They are important, and many are of a nature that is next to impossible to do unless electronic simulators are used. But their nature is more of an orderly step-by-step analysis of the various factors involved. If no serious problems are encountered, a logical design should result. If, however, an impasse arises, the studies serve as a basis for stimulating creative thinking, and electronic simulators serve as powerful analysis tools.

For example, long before any electronic simulators are used, considerable "paper-work" analysis is performed. The most customary paper-work technique is that which uses conventional linear control system design procedures. Now there is nothing linear about the equations that define the motion of an air frame, except under limited restrictions as to altitude, speed, and angle of attack. Similarly, there is nothing linear about space angles that always involve trigonometric functions, except within very small angular movements. Nevertheless, linear theory serves us well and enables most effects to be evaluated. Always, however, the designer must stop and consider the fact that even though linear theory is easier to use and its results easier to analyze, this does not mean that the optimum system—as far as production cost, simplification, and accuracy—has been achieved.

One example of an application arose in the design of a *g*-limiting device. We wanted the air-frame maneuver to be limited to a certain number of *g*'s. Using linear theory we could design the system so that the input voltage (representing a *g* demand) could be limited in order not to exceed a certain value. Then the output, in the steady state, would not exceed the same value. However, all linear systems, unless they are damped so that they take a long time to respond, overshoot the input demand. Since the dynamic characteristics of an air frame may change radically with speed and altitude, the overshoot magnitude is not constant. In some cases it would be 10 per cent more than the demand; in others, it would be as much as 50 per cent. This meant that in order not to exceed the design value, linear theory required that the system be set for 67 per cent of the design value. Then, overshoots of 50 per cent would just meet the design limit (but only during the transient period), and overshoots of 10 per cent

would call for a maximum of somewhat less than 75 per cent of the design value. This limited the air-frame capabilities.

We found that a linear system combined with a nonlinear override system improved performance considerably. Briefly, it works in this way. The linear system was designed for adequate stability, but no restriction was placed on the input demand. Thus, if the full design value were applied, the linear system by itself would respond as fast and stably as possible and, in fact, would overshoot by as much as 50 per cent. The nonlinear override system is activated when the acceleration output is 90 per cent of the design value. Immediately, it cuts the input demand to zero and also applies a negative pulse to the control surfaces which effectively stops the output acceleration just before the design value is reached. When the output acceleration falls below 90 per cent of the design value, the override system drops out, and the linear system continues until the same situation again arises.

We have found that override systems often appreciably improve performance. However, electronic simulations are definitely required for their development. Another case arose in the range stability of a missile. As the missile neared the target, the range became smaller. In the analysis of the system it could be shown that the inverse of the range was a system gain. Thus, an extremely high gain occurred in the system at small ranges, and the navigation system actually became appreciably unstable. An override system again proved quite promising.

On the other hand, we have found that in some cases a linear system can be better than a nonlinear system. This arose in one case where we thought that meeting the design requirement was difficult, using a linear system. We explored nonlinear possibilities and found a good solution. However, close study of the nonlinear system indicated that a linear device similar to it should be satisfactory. When this linear arrangement was used, good results were obtained.

It is interesting to follow the pattern of problems that are given to an electronic simulator. When the equipment first arrives in an engineering section, the problems given it are few. Then, one by one, the various engineering groups stroll over to the man in charge of the computer, say they have a problem that is such and such, and ask, "Can The Brain handle this?" Usually these problems are quite routine and involve manually tedious calculations, and usually the computer can solve them much more efficiently. As each of the engineering groups find out about this wonderful machine, they bring over many more problems, and these are still of the routine type. Often they are also extremely simple.

Over a period of time, many routine problems are solved—in fact, so many that the problem-giver begins to know the pattern of the solutions, and soon he knows what the answer will be before The Brain has had its chance. Now, something new develops. In place of routine problems, the designer wants more complicated and detailed problems solved. As he becomes more familiar with simulator operation, he experiments with control techniques and takes fuller advantage of the computer capabilities.

Electronic simulators are useful for flight evaluation. Several types of information are desired. Was the flight performance as predicted? Do the air-frame characteristics agree with wind-tunnel or estimated values? Was the controller operation proper?

It should be anticipated that these questions will arise after a flight. Therefore, certain preparations are required. For example, a low-altitude flight may require very small control-surface deflections that call for extremely accurate telemetering information. Another flight plan may require larger movements but, at the same time, appreciable changes in trim positions. If the purpose of a flight is to evaluate certain characteristics, the entire flight should be accurately simulated prior to the flight test, and the information obtained from the simulation should be used to select signal levels for the telemetering channels. This sounds rather obvious, yet it can be overlooked. Certain inputs are much more informative than others. For example, a step input into a system that reponds in a few hundredths of a second yields telemetering information that is practically useless. Similarly, a sinusoidal input of a frequency too far removed from the air-frame natural frequencies may also yield little information.

Once a flight has been performed, additional problems may arise which require simulators. On one of our flight tests, we found that the missile was subjected to a 12° roll due to launcher effects. Analysis showed that both the magnitude and the direction would be reasonably repeatable. Each time the missile would roll 12° and return to 0°. This magnitude was too high for compatible operation of the entire system. Simulator studies showed that it could be reduced approximately 50 per cent by increasing the roll-system gain. This was feasible. Larger increases in the roll gain introduced other design problems. While a 50 per cent increase in gain brought the roll down to 6°, this was just on the border line of satisfactory operation. Offsetting the control surfaces slightly yielded a system within tolerances and one that first rolled 3° in one direction, then 3° in the other direction. These studies were performed between the first and second flights. The electronic simulators played a useful and speedy part in this study. In addition to the immediate solution discussed above, the simulators also helped us develop even better solutions that could be incorporated later.

In conclusion, let us reverse the initial question and ask, "What can the missile designer do for electronic simulators?" The answer is *think*, and this is spelled *think*, not in the currently popular manner *thimk*. Thinking must take place before the problem is set-up so that the proper equations and conditions are represented. While the problem is being solved, the designer should have a good idea of all the different re-

sults he expects, and he should be fully prepared to alter the problem in order to explore important answers. After the problem has been solved, thinking is again important. The designer should carefully consider exactly what has been accomplished, how it could have been improved, if the problem was necessary at all, and what his approach will be on the next similar problem.

I have discussed some of the typical problems that have made electronic simulators more than just helpful tools. As we learn more and more about design techniques, we find that we become practically completely dependent on electronic simulator help. We also develop a deep respect for these machines and feel they are largely responsible for the progress that has been made in the missile field.

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Analog Equipment for Processing Randomly Fluctuating Data

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ABSTRACT

Experimental studies of buffeting, flutter, and atmospheric turbulence produce data which are not amenable to analysis by the usual process of measuring or calculating discrete values of static force, pressure, or moment. Instead, where randomly fluctuating quantities are involved, it becomes necessary to use statistical methods to analyze and describe the phenomenon being investigated. The types of information usually required are probability distributions, power spectra, and cross spectra.

In order to avoid the time and expense involved in using conventional numerical methods for securing the various statistical analyses, the NACA uses a technique of recording data on magnetic tape and playing it back into electronic analog analyzers which perform the desired analyses and automatically plot the results.

The magnetic tape recording system and the analog analyzers are described in this paper and their application to aeronautical problems is illustrated. A discussion of the comparative accuracy and reliability of the numerical and analog methods is also included.

(I) INTRODUCTION

IN MUCH OF THE EXPERIMENTAL WORK undertaken in aeronautical research and development it is possible to set up experiments so that the amplitude of any quantity being measured remains very nearly constant during a given test run. In this case a precise measure of the static level is sought and any fluctuations in the level occurring during the run are considered to be "noise" which must be eliminated by filters or faired through on the time-history record.

However, many phenomena being studied produce data in which random amplitude fluctuations are inherent and measurement of average or faired levels only is of little or no value. Typical examples are gun aiming errors encountered in fire control systems, loads imposed on airplanes by turbulence or buffeting, stresses produced by engine noise or vibration, and aircraft landing gear loads caused by rough runways. In these cases, the information sought must be secured by analysis and study of the random amplitude fluctuations about the mean value.

The most practical way to describe quantitatively these amplitude variations is to use the statistical techniques which have been devised for analyzing stationary random time series. The simplest and most familiar of these techniques is the probability distribution, which, for example, has been used for years to describe atmospheric turbulence. Recently, the generalized harmonic analysis techniques have been developed and are being successfully applied to many random-type data analysis problems.

The theoretical aspects of these techniques have been discussed by Wiener,[1] Tukey,[2] and Rice,[3] and specific applications to aerodynamic problems have been described by Clementson,[4] Liepmann,[5] Summers,[6] Press,[7] Chilton,[8] and others.

These authors have demonstrated that statistical techniques are extremely useful in aeronautical research. However, if conventional time-history records and numerical data work-up procedures are used to secure the various required analyses, the application of these techniques to actual samples of experimental data is a time-consuming and expensive process. This is especially true in the case of power and cross spectra determinations. In addition to the digital computer expense involved in making the thousands of required numerical calculations, several days may be required to read the necessary number of data points from the time-history record. These factors often seriously restrict the number of statistical analyses that might be made, or force one to limit severely the length of the data samples and to accept the consequent poor statistical reliability.

To overcome these limitations the NACA has combined commercially available electronic equipment with NACA-developed components to provide an analog data processing facility which produces the required statistical analyses rapidly and inexpensively. This facility consists of four basic elements: (1) magnetic tape data storage and playback system, (2) a probability distribution analyzer, (3) a power spectral density

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*Aeronautical Research Scientist, Instrument Research Division.

analyzer, and (4) a cross spectral density analyzer. This paper will describe these pieces of equipment, in the order listed, and will briefly illustrate the application of the various types of analyses to aeronautical research.

(II) Magnetic Tape Recording and Playback System

An essential part of the data processing facility is the magnetic tape recording equipment illustrated in Fig. 1. This equipment provides a means for storing the data in such a way that it can be accurately reproduced in a form most suitable for analog processing.

Instead of recording data directly on magnetic tape a frequency-modulated carrier system is used. This permits the storage of very low frequency and d.c. data and eliminates much of the spurious amplitude variation which would otherwise be caused by tape imperfections and tape wear. It also makes possible the direct recording of FM radio telemeter data.

Where the data to be processed are produced by a stationary facility such as a wind tunnel, the tape recorder and FM modulators are located at the facility. Where the data are produced by an airplane, helicopter, or rocket-propelled missile, the data are transmitted to a tape recorder on the ground by a radio telemeter link. Or, if the data to be processed have been previously recorded as a trace deflection on photographic paper or film, a transcribing machine is used to convert film deflections to a frequency modulated carrier which is recorded on tape.

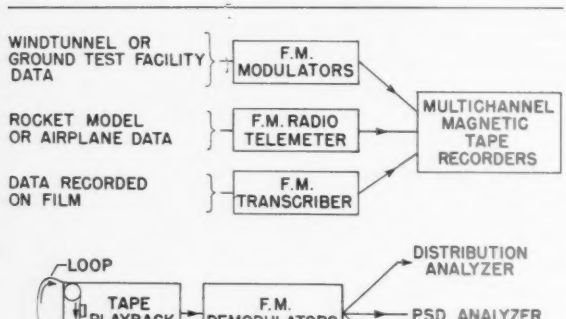

Fig. 1. Magnetic tape-recording system.

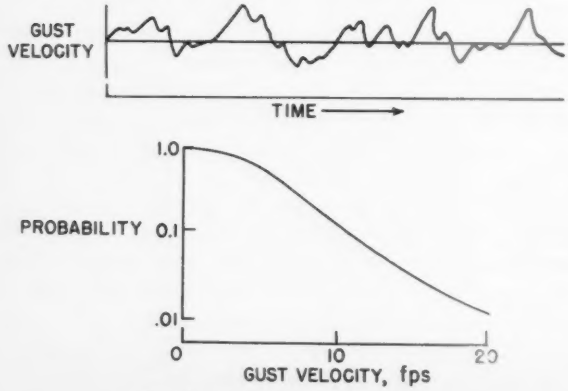

Fig. 2. Probability distribution.

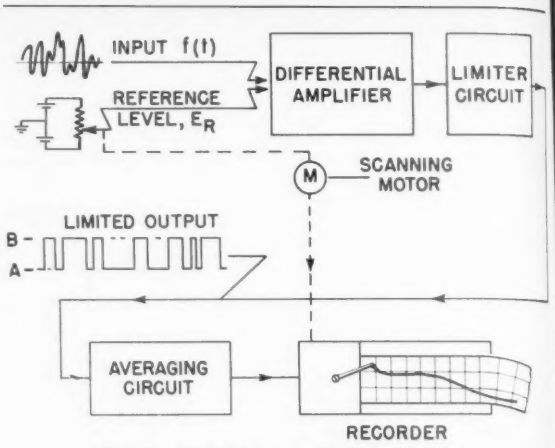

Fig. 3. Probability distribution analyzer.

Use of magnetic tape recorders provides a great deal of flexibility in handling data samples. Sample lengths and frequency ranges can be expanded or compressed by factors as high as 240 to 1 simply by changing the tape speed. Data samples from 1 sec. to several minutes in duration and containing frequencies from d.c. to 6,000 cycles per sec. or 7,000 cycles per sec. can be recorded and reproduced by the FM system. If necessary, higher frequencies can be handled by eliminating the frequency modulated carrier and recording directly.

The analog analysis methods require that data samples be scanned a large number of times by the analyzing equipment. Consequently each sample on the tape is spliced into a continuous loop before being played back into the FM demodulators and the analyzers.

The three types of analyzers through which data recorded on tape may be processed are a probability distribution analyzer, a power spectral density analyzer, and a cross spectral density analyzer. These three analyzers and the type of statistical information produced by each will be discussed in the following sections of this paper.

(III) Probability Distribution

The time function shown at the top of Fig. 2 illustrates a randomly varying quantity of the type to be considered throughout this paper. One way to analyze such a function is to determine its probability distribution. This is a measure of the proportion of total time during which the amplitude of the varying quantity exceeds given levels.

For example, suppose the time function shown at the top of the figure were a plot of the gust velocities encountered by an airplane flying through rough air. The intensity of the turbulence could be shown by plotting the probability that the gusts would exceed specific velocities against gust velocity. The gusts in the atmosphere represented by the distribution shown would

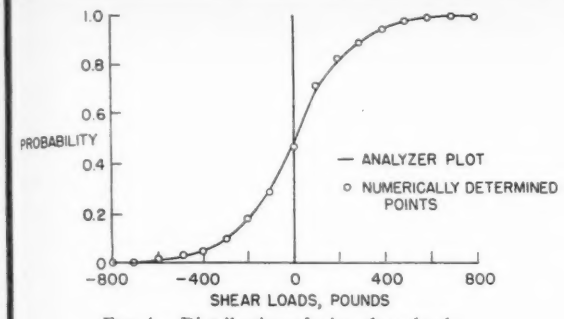

FIG. 4. Distribution of wing shear loads.

be expected to exceed 3 or 4 ft. per sec. about 95 per cent of the time and to exceed 20 ft. per sec. only about 1 per cent of the time.

The electronic analyzer used to determine probability distributions is illustrated in Fig. 3. The data sample recorded on an endless loop of magnetic tape is continuously played into the analyzer, and its instantaneous amplitude is compared to a reference voltage E_R. The level of the reference voltage is determined by the position of the potentiometer slider. If the input voltage is larger than the reference voltage, the amplifier will be saturated and the output of the limiter will be at level B; if the input is less than the reference voltage, the amplifier will be cut off and the output of the limiter circuit will be at level A. The percentage of time that the level is at B then represents the probability of the input being above the fixed level E_R. By averaging the output of the limiter this probability may be read directly and recorded. By slowly changing the level of the reference voltage and driving the paper on the recorder in synchronization, a complete plot of the probability distribution may be obtained.

To illustrate the use of the analyzer, Fig. 4 shows a distribution of wing buffeting loads obtained during a gradual pull-up at high speeds. The solid line is the analyzer record and the circled points are values determined numerically. Set-up and running time on the electronic analyzer was about 20 to 30 min. and about 7 man-hours were required to read the time-history record, calculate the mean, and determine numerically the circled points.

(IV) Power Spectral Density

The probability distribution describes the intensity characteristics of the data but does not describe their frequency or spectral characteristics. Nor does it furnish information sufficient for calculating system input-output relationships or transfer functions. If this sort of information is required, a second type of statistical analysis called the power spectral density analysis may be used.

Power spectral density analysis is sometimes referred to as "generalized harmonic analysis" and is similar to the familiar Fourier series harmonic frequency analysis except in the following respects: (1) Fourier series analysis is applicable to repetitive functions while generalized harmonic analysis is applicable to stationary random time functions, (2) as illustrated in Fig. 5, the spectrum is represented as a continuous curve rather than as discrete harmonically-related frequencies, and (3) the spectrum is plotted in terms of mean-squared amplitude per unit bandwidth (equivalent to average power per unit bandwidth in the electrical system) instead of simple sine-wave amplitudes.

The power spectrum then represents the distribution of energy over the frequency spectrum. For example, the portion of the total energy included in the frequency band f_1 to f_2 in the figure is represented by the area under the curve between f_1 and f_2.

One extremely useful feature of the power spectra concept is the simple input-output spectra relationship illustrated in Fig. 6. For linear systems, the power spectral density of the system's output $G_o(f)$ is equal to the power spectral density of the input $G_i(f)$ times the squared absolute value of the transfer function $Y(f)$. Thus, we have a relationship among the three variables such that if two of the three are known, the third may be determined.

This sort of input-output-transfer function relationship is one which is familiar to the electrical engineer who is often fortunate enough to be able to work with strictly sinusoidal signals. It should be noted that the power spectra concept now enables the aeronautical engineer, who often has no choice but to work with ran-

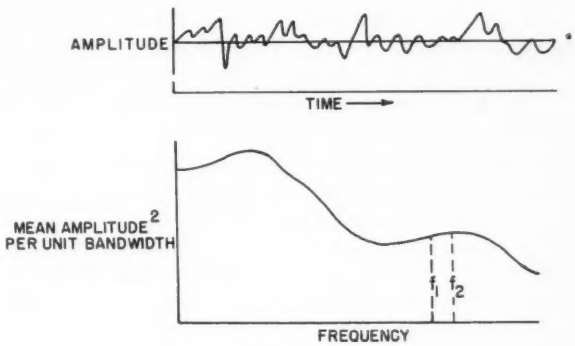

FIG. 5. Power spectral density.

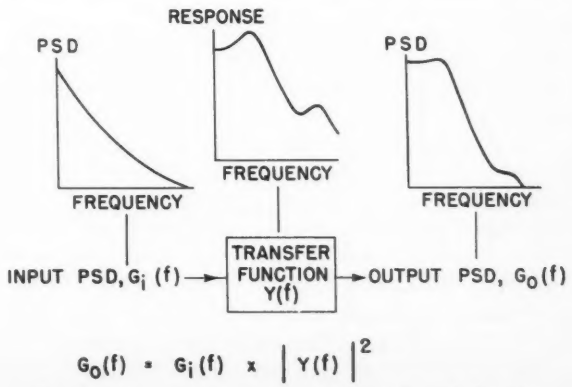

FIG. 6. Input-output power spectral density relationship.

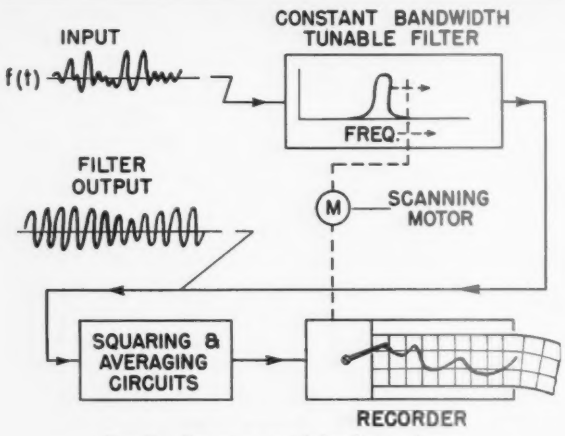

FIG. 7. Power spectral density analyzer.

domly fluctuating type of "signals," to perform the same sort of "circuit analysis" as the electrical engineer.

For example, again consider the problem of an airplane flying through rough air; the airplane can be considered as a mechanism having a transfer function $V(f)$, the turbulence can be considered to be the input $G_i(f)$, and the airplane's response can be considered as the output $G_o(f)$.

Thus, by measuring an airplane's transfer function and its response to atmospheric turbulence, it is possible to use the plane as an instrument for measuring turbulence, as Clementson[4] and Summers[6] did. Or, if a specific turbulence spectrum is assumed and the airplane's transfer function is known, it is possible to predict the plane's response to the turbulence.

Also, by using the techniques developed by Rice,[3] it is possible in many instances to use power spectra to calculate such things as the number of zero crossings and the number of times the amplitude of a randomly varying quantity exceeds certain levels.

Power spectral density may be numerically calculated by a procedure outlined by Tukey.[2] Very briefly summarized, this procedure is as follows: First, read the time-history record point by point; second, calculate the autocorrelation function of the data sample by evaluating the integral

$$\int_0^T f(t) \cdot f(t + \tau) dt$$

for several discrete values of time lag τ; and third, determine the power spectral density of the data by taking the Fourier cosine transform of the autocorrelation function.

This process is equivalent to passing a tunable, constant-bandwidth filter of known characteristics over the data and measuring the time average of the square of the filter's output. Except for squaring of the filter's output and some difference in the filter's characteristics, the results are almost identical to those obtained from the familiar spectrum analyzers that have been used for years by communications and sound engineers.

This suggests then that there are two types of electronic analog equipment which might be used to determine power spectra: one type parallels the numerical process by first determining the autocorrelation function and then taking its transform to get power spectral density; the other omits the autocorrelation function entirely and measures the spectrum directly by means of a scanning electrical filter.

Since scanning filter types of analyzers are comparatively simple electronic devices and are commercially available, the NACA uses the direct spectrum measurement approach.

This type of analyzer is illustrated in Fig. 7 and operates in the following manner. The data sample stored on a continuous loop of magnetic tape is applied to the bandpass filter. Any frequency components in the data which fall within the filter's pass band will be passed by the filter, squared, averaged, and then applied to a direct-writing recorder. The filter is initially set at the low end of the frequency range and slowly scans upward through the spectrum until the entire frequency range of interest has been covered; at the same time the recorder paper is moving under the stylus so that a continuous plot of power spectral density against frequency is obtained.

The scanning speed of the analyzer is normally conservatively adjusted so that about three passes of the data sample on the loop are made during the time required for the filter to scan one filter bandwidth. Under these conditions, the time required for complete analysis of a typical record is 10 to 15 min. Faster scanning speeds may be used, but some "smearing" of the spectrum might result.

The bandwidth of the scanning filter in the NACA's equipment can be adjusted to values ranging from 1/2 cycles per sec. to 200 cycles per sec. and the true-time range of frequencies which can be analyzed is from 3 cycles per sec. to 15,000 cycles per sec.

By taking advantage of the possible changes in tape speed previously mentioned, it is possible to obtain equivalent filter bandwidths of 0.01 cycles per sec. or less and to handle frequencies ranging from a few hundredths of a cycle to 50 or 60 kc. By changing tape speeds where necessary, it is also possible to handle

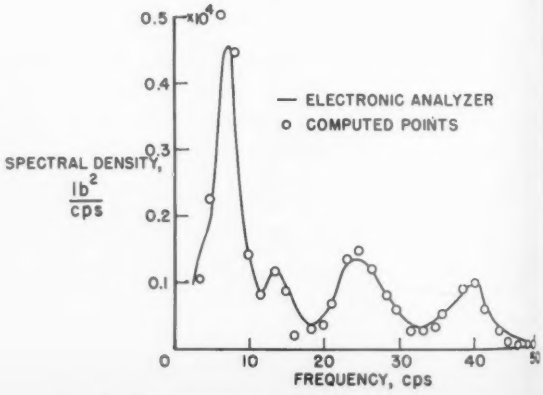

FIG. 8. Power spectral density of wing shear loads.

record lengths ranging from a few tenths of a second to several minutes in duration.

To illustrate the use of the power spectrum analyzer, Fig. 8 shows the spectrum of the shear loads on a fighter-type airplane wing under buffeting conditions. The continuous curve was obtained from a magnetic tape record played through the analyzer and the circled points were obtained by reading the time-history record and numerically calculating the spectrum.

The results from the two methods differ by a maximum of about 10 per cent at the low-frequency end of the spectrum. This difference is due, in part at least, to a large, undesired, very-low-frequency component in the original data sample which had to be attenuated before the analysis. The electrical high-pass filter used to attenuate this component was not identical to the equivalent numerical high-pass filter used for the same purpose; therefore, some differences in the spectrum at the low-frequency end were to be expected.

Some difference between the analyzer and the numerical values also result from the fact that the shape and bandwidth of the analyzer's scanning filter were not identical to the equivalent filter resulting from the numerical process.

Actually, differences of 10 per cent are not particularly alarming. We are dealing with statistical processes such that, even with errorless data processing schemes, the results obtained from repeating the same test might easily vary as much as plus or minus 25 to 30 per cent. More will be said about this subject later.

Here, to read the record and determine the spectrum using an automatic digital computer required about 10 man-hours; the time required for setting up and running the electronic analyzer was less than 30 min.

(V) Cross Spectral Density

It has been shown that the power spectral density furnishes information regarding the frequency content of fluctuating quantities which is not provided by the probability distribution. However, where the phenomenon being investigated involves study of two or more related fluctuating quantities, which is usually the case, some knowledge of the time or phase correlation between the two quantities might also be required. This information is not provided by the power spectra of the individual functions but may be obtained from another statistical process called cross spectra analysis.

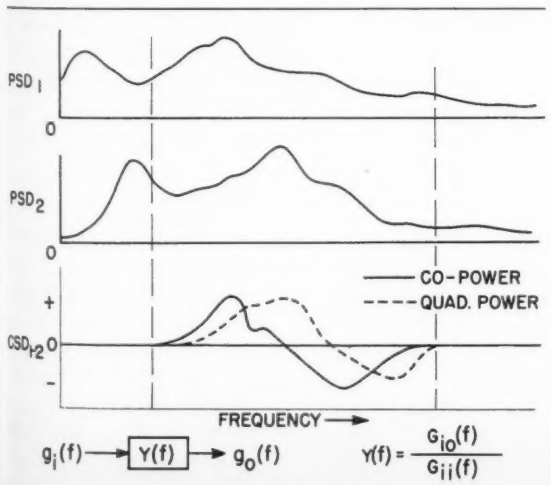

Fig. 9. Cross spectral density.

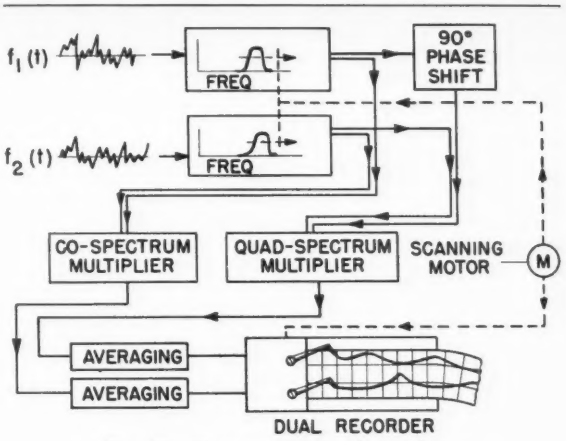

Fig. 10. Cross spectral density analyzer.

The cross spectrum between two time functions is a vector quantity and two spectra are required to furnish the complete cross spectral density. These are illustrated in Fig. 9. The real part is called the "co-power spectrum" and indicates the product of the in-phase frequency components in the two functions. The imaginary part is called the "quadrature spectrum" and indicates the product of the 90° out-of-phase frequency components in the two functions. The absolute value and phase angle of the cross spectrum are determined by vectorially combining the in-phase and quadrature spectra.

To gain an understanding of the physical significance of cross spectra, consider two fluctuating time functions whose power spectra are represented on Fig. 9 as PSD_1 and PSD_2. The cross spectrum between the two functions will indicate only those frequencies in PSD_1 which are also contained in PSD_2 and which bear a specific, nonrandom phase relationship to the frequencies in PSD_1. For example, PSD_1 and PSD_2 may include power in the same frequency band, but, if the corresponding frequency components are entirely independent of one another, the phase between them would be random and the cross spectral density would be zero throughout the band. However, if some of the frequency components in PSD_1 bear a definite phase or time relationship to the corresponding components in PSD_2, this relationship will be indicated in the cross spectrum.

One useful application of the cross spectrum is in the determination of the phase response of a linear system subjected to a random-type input. Recall that the power spectra of the input and output made possible calculation of the absolute amplitude of a system's transfer function but did not furnish any knowledge of the phase response. By using cross spectra, both the amplitude and the phase response may be calculated.

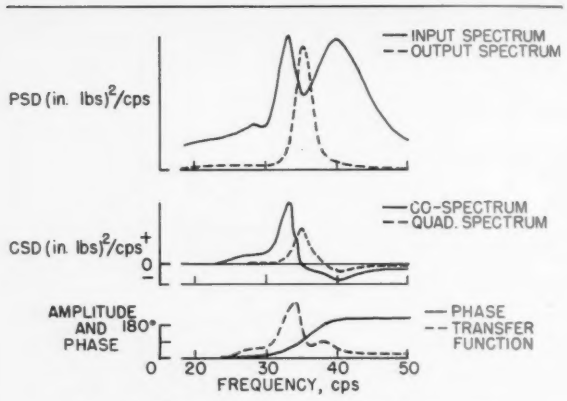

FIG. 11. Cross spectra of wing bending moment.

As shown by Lee,[9] the transfer function $Y(f)$ equals the input-output cross spectrum $G_{io}(f)$ divided by the power spectrum of the input $G_{ii}(f)$.

An interesting feature of this relationship is the fact that the equation holds true even though other independent random noises are present in the output. This is true since the input-output cross spectrum will ignore the presence of uncorrelated random fluctuations in the output.

The cross spectra has other useful, practical applications to systems with multiple inputs and outputs, but these are too involved to discuss here. A good illustration of this usage, however, is included in Summers' paper on atmospheric turbulence measurements.[6]

The numerical process for determining cross spectra is even more lengthy and expensive than that required for determining power spectra. However, the numerical results can be duplicated by the analog process illustrated in Fig. 10. The two fluctuating data samples recorded on a continuous loop of dual-channel tape are simultaneously applied to two synchronized filters of the same type used with the power spectral density analyzer. However, instead of squaring and averaging the outputs of the filters as would be done to determine power spectra, the two outputs are fed into a multiplier whose output is averaged and automatically plotted against frequency to furnish the co-power spectral density. At the same time, one of the filter outputs is run through a 90° phase shifter and again multiplied by the output of the other filter. The product is then averaged and plotted to give the quadrature power spectral density.

To illustrate the use of the cross spectrum analyzer, Fig. 11 shows some data secured from a buffeting airfoil in a supersonic wind tunnel. The double-peaked spectrum is the power spectral density of the fluctuating aerodynamic forces existing at a particular spanwise station and the single-peaked spectrum is the power spectral density of the fluctuating bending moment existing at the root of the wing. The cross spectral densities between these two quantities as determined by the analyzer are shown in the center of the figure. The calculated amplitude and phase response shown at the bottom of the figure indicate that the wing is similar to a spring-mass system with low damping. (This simple example does not provide aerodynamic data of any particular value but was chosen to demonstrate the use of the analyzer and the type of problem to which it is applicable.)

To set up and run these four spectra on the electronic analyzers required about $1\frac{1}{2}$ hours. To read the time-history records and run the same four analyses digitally would require an estimated 40 to 50 man-hours—which explains why no numerically calculated check points are shown in the figure.

(VI) Accuracy and Reliability Considerations

Electronic analog analyzers might introduce errors in the order of plus or minus 10 per cent where a digital computer can process data to almost any degree of precision that might practically be desired. Consequently, a given data sample can be statistically analyzed by a digital computer more precisely than by an analog machine.

However, it must be remembered that we are dealing with statistical quantities. Consequently, if an experiment or test is repeated several times, sizeable variations in experimental results occur even if the instruments and analyzing processes introduce no error at all. For example, consider again the wing loads power spectrum, previously shown in Fig. 8, which is fairly typical of the type of problems encountered. The statistical reliability in this case was such that only one out of three tests would be expected to yield power estimates within plus or minus 10 per cent of the true value. If the length of the data sample could be increased by a factor of 20, however, 19 out of 20, instead of 1 out of 3, of the tests would be expected to yield results within plus or minus 10 per cent of the true value.

In analysis of actual data samples, then, consideration of the statistical aspects of the problem usually shows that improved reliability might be obtained, not by improving computational accuracy, but by analyzing longer data samples.

Longer samples are not always possible, especially in airplane or missile flights, where steady flight conditions often cannot be maintained for longer than a few seconds. Where longer samples can be secured, however, the electronic analyzers can economically handle samples of such length that analysis by any other process would be quite impractical.

(VII) Concluding Remarks

In conclusion, the various statistical analyses required in aeronautical research and development can be secured rapidly and economically by the use of electronic analog analyzers. The accuracy of the analog analyzers in processing a specific data sample is somewhat inferior to that available from digital computers. This factor is normally outweighed, however, by the analog equipment's capability for economically handling longer data samples and providing improved statistical reliability.

It appears that more extensive use of the analog analysis techniques might facilitate further advancement in the application of statistical methods to aerodynamic problems.

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A Compass-Controlled Directional Gyro System for Today's Fighter Aircraft

(*Continued from page 79*)

tem. The right-hand knob is used to set in the latitude of flight to provide latitude correction of the drift effect of the earth's rotation during free-gyro operation. The center knob selects the mode of operation—i.e., compass-slaved, free-gyro with latitude correction in the northern hemisphere or free-gyro with latitude correction in the southern hemisphere. The controller is designed for standard console mounting (Specification MIL-C-6781) and indirect illumination (Specification MIL-P-7788). The weight of the controller is 1.5 lbs.

The amplifier servo unit (see Fig. 7) serves several functions. It contains the leveling, slaving and servo amplifiers, system power supply, and servoed output, and is the junction box of the system. This latter feature eliminates the need of additional junction boxes. A trim control is available which electrically balances the gyro over a range of ± 2° per hour. This permits trimming the system on installation to obtain the maximum accuracy of the gyro if desired. By the use of plug connectors on the servo unit (Fig. 8) and the compass-slaving amplifier, all components are easily accessible for servicing. The weight of the amplifier with its mounting rack is 8.7 lbs.

The MA-1 Compass System employs an improved directional gyro permitting a free-gyro drift rate of less than 4° per hour. This is possible because no load is reflected back to the gyro from the repeaters or navigational equipment. When slaved to the earth's magnetic field through a modern remotely mounted compass, accurate, stabilized heading information is constantly available through 360° in azimuth.

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The Flight Simulator Modification Problem

(*Continued from page 108*)

In Conclusion:

(1) The present state of the art provides standardized simulator components having a high level of performance, reliability, and the necessary universality to accommodate changes in aircraft characteristics.

(2) Simulators can be kept current with aircraft changes if the simulator manufacturer is delegated authority to initiate changes and has the cooperation of the aircraft manufacturer in furnishing change notices, data, and parts.

A Flight Investigation of the Performance of Low-Ceiling Visibility Measuring Equipment

R. P. SNODGRASS*
Sperry Gyroscope Company

The History

THE FLIGHT PROGRAM that is the subject of this paper had its beginnings in an Actual Weather Low Ceiling flight-test program conducted by the Flight Research Department of the Sperry Gyroscope Company in 1950 through 1952. In this program a DC-3 was operated into airports in the New York terminal area under weather conditions that were, in general, below air-line minimums. The primary purpose of this program was to evaluate flight instruments and automatic flight control equipment, products of the Sperry Gyroscope Company, and to study the operational problems associated with low weather flying. One of the results of the operational study phase of this program was an analysis of weather observed from the cockpit as compared to the reported weather existing at the airports. This analysis showed considerable discrepancy between the cockpit weather and the reported weather. This was some of the first documented evidence on a problem that had been the subject of a great deal of discussion in past years. As a result of work on this program, the Air Navigational Development Board approached the Sperry Company in 1952 with respect to conducting a flight investigation of the performance of new types of weather measuring instrumentation developed by the Weather Bureau and the Bureau of Standards. This instrumentation consisted of the 5-r.p.m. rotating beam ceilometer and the transmissometer. A contract was awarded the company for an operational evaluation of this equipment and a study of the problem of weather as seen from the cockpit. This investigation was concluded in 1954.

The Problem

On an instrument approach, what the pilot really wants to know is not the value of the ceiling and visibility but rather at what points on the approach he will be able to see those things that he needs to see in order to complete the approach to a visual landing. To accomplish this, a number of factors must be defined. First of these is, of course, the weather—that is, the state of the atmosphere from the standpoint of transmission of light. Second, what are the configuration, the beaming characteristics, and the intensity of the lights which bound the runway, define the threshold, and make up the approach light system? Third, what is the state of ambient light—namely, is it day, twilight, or night? Fourth, what are the conditions of light reflectance of terrain surrounding the runway and in the approach zone? Is the approach terrain made up of trees, farms, roads, or houses, or is it an industrial area? Is it an open sea? Does the runway have painted markings? Is the sun ahead of or behind the aircraft? These factors and others affect what is called the "transition"—that is, the change that occurs in the method of control of the aircraft from flight by instruments to visual flight following the breakout.

Fig. 1 illustrates three successive and significant steps as they occur on a given approach. The first significant event that occurs is "vertical contact." This is the point on the approach where the pilot's initial visual reference with the ground is obtained. Usually the earliest visual reference is obtained through the side windows of the cockpit and is in a near-vertical direction. This point is significant in that it marks the beginning of the transition to visual flight. The second point is "approach light contact." This particular point on the approach could, of course, be the same as the "vertical contact." Approach light contact is important because it defines the beginning of visual reference to lights that may be necessary to complete a visual approach to the runway. The third event is "threshold contact." This marks the point at which the pilot first sights the end of the runway, and where judgments relative to the landing can first be made. One common element of these three points on the approach is significant—namely, each is a distinct and definable event as far as the cockpit is concerned. The final item of importance to the pilot is, of course, runway visual range. This factor affects the landing and the roll-out.

Presented at the Air Transport Session, Twenty-Third Annual Meeting, IAS, New York, January 24–27, 1955.

* Chief Engineering Test Pilot.

The problem, then, was to determine if the new weather measuring system could be used to predict the three points on the approach of vertical, approach light, and threshold contact and the runway visual range.

The Program

The flight-test program that was conducted in cooperation with the Weather Bureau and under contract to the ANDB involved the correlation of the three points—vertical, approach light, and threshold contact—as seen from the cockpit with the weather observations made on the airport and in the approach zone. The purpose of this correlation was to determine the accuracy with which these given points could be predicted when based upon surface observations.

The surface equipment used in this program was installed at MacArthur Airport, Long Island, and may be seen in Fig. 2. The two items of new weather measuring test equipment are, of course, the 5-r.p.m. rotating beam ceilometer and the transmissometer. Supporting photometric instrumentation was a terrain illuminometer and a manually operated photometer for obtaining background luminance and reflectances of runway, runway markings, and terrain. Supporting observations of meteorological visibility were made, as were the usual Weather Bureau Circular N-type observations. The runway itself was marked with a modified Calvert-type runway marking system. The runway lights were of high-intensity HRL type with the Air Line Pilots Association threshold lighting configuration. British-type "pup-tent" markers were installed on each side of the runway. Approach lights were of the neon bar type.

Aircraft instrumentation may be seen in Fig. 3. A movie camera was used to photograph through the windshield. A "visible terrain" camera was used to photograph a solid angle of approximately 80° in azimuth and 80° in elevation. Photo-recorders registered various instrument readings on the instrument approach. A continuous radio link permitted comments and observations made by the copilot and pilot to be transmitted to the ground test station for recording. In the ground test station all of the surface observations were documented, and these were synchronized in time with the air-borne data and the pilot's comments.

The flight-test program utilized a DC-3, and all approaches were made using the A-12 gyropilot and automatic approach on the MacArthur Instrument Landing System. Actual weather test approaches were made both day and night, with the maximum emphasis on weather below 500 ft. ceiling and 1-mile visibility. Tests flights began in January, 1953, and were concluded at Idlewild in February, 1954. A total of 468 actual weather instrument approaches was accomplished in this program.

The Results

The test data obtained during the program were analyzed on a general basis. Pertinent photometric factors involved in the determination of visual ranges from the aircraft to the ground were considered. The results of the analysis may be applied to the determination of corresponding visual ranges at other airports.

The visual detection and/or recognition of objects, patterns, or lights from the cockpit during an approach are dependent upon the following conditions:

(1) The meteorological constitution of the atmosphere along possible lines of sight between the aircraft and the ground.

(2) The photometric distribution of ambient sky and ground luminances as well as the candle-power distribution of self-luminous ground sources, such as lights.

(3) The psychophysical factors involving the pilot, such as his brightness-contrast threshold and his illuminance threshold.

The exact solution to the problem of determining the visual range from the cockpit depends upon complete information relative to the heterogeneous distribution of the atmosphere, the ambient photometric quantities, and the precise visual threshold applicable to the pilot. It is evident that a few sample meteorological and photometric observations taken at an airport are insufficient to supply all of the foregoing information. The indeterminate character of the problem thus presented makes the solution in terms of the concept of probability an appropriate one. The results obtained in this program have, therefore, been expressed in terms of the probability of realizing visual reference at or before reaching a given height on the glide slope. This height can, of course, be converted to a range from the runway threshold. Meteorological and photometric observations are used as parameters. This probability will vary between some value near zero as a lower limit and nearly unity as an upper limit over an interval of heights. Upon the assignment of practical lower and upper limits of probability, say 0.05 and 0.95, the corresponding difference in associated heights will be a measure of the accuracy of the determination of visual range. Small height difference will correspond to accurate determinations.

All data were classified into three meteorological categories. These were (1) ceiling condition, (2) radiation fog, and (3) snow. The radiation fog and snow classifications cover special conditions of restricted visibility with meteorological characteristics readily recognized by a weather observer. All other conditions involving obscuration to vision by clouds and fog were grouped under the general "ceiling" caption. Data pertaining to atmosphere pollution, such as smog, smoke, and haze, were not obtained in any significant quantity in this program.

The results of the analysis are based on ceilometer and transmissometer observations that were made concurrently with the aircraft approach—i.e., there was no significant time delay between the surface observations and the visual cues received by the pilot. The problem of forecasting on even a short-term basis, as will be required in practice in an actual airport operation, was not within the scope of the program.

Two factors—aircraft type and the means used to couple the aircraft to the ILS—have influenced the results obtained in this program. With regard to the aircraft type, the cockpit and windshield configuration affects particularly the vertical contact height and, under low-visibility conditions, the approach light contact. Vertical visual reference, generally obtained through the side windshield, is dependent upon the aircraft lateral cockpit cutoff angle. Approach light contact, under low-visibility conditions, is usually obtained at large angles below the horizon and is therefore contingent on the forward cutoff angle.

The coupling to the ILS provided by the A-12 gyropilot-automatic approach produced optimum conditions for the pilots to make visual observations during the approaches. Furthermore, since repeated approaches were accomplished during the test program, maximum familiarity with the weather conditions was afforded the pilots. Consequently, it is felt that the results obtained indicate the earliest visual recognition that could be achieved.

The results of the Idlewild flight tests covering a very limited weather spectrum were consistent with the general results based on the MacArthur Field data.

To illustrate the results of the program, probabilities for obtaining specific visual reference cues will be indicated for a given sample condition. The selected conditions are as follows:

Weather Parameters

Classification—ceiling type
Average ceilometer indication = 400 ft.
Standard deviation of ceilometer indication = 30 ft.
Transmissometer indication = 0.50

Photometric Parameters

Daytime—terrain illuminance = 300 foot-candles
Horizon luminance = 200 foot-lamberts
Reflectance difference between runway and contrasting background of runway markings = 0.2
Reflectance of brighter or contrasting areas = 0.6
Reflectance difference between two contrasting portions of runway marker (pup-tent) = 0.6
Reflectance of lighter half of pup-tent = 0.8
High-intensity threshold lights—ALPA configuration, type HRL fixtures with green filter (8,710 c.p. maximum)
Setting—No. 5, 100 per cent intensity
High-intensity runway lights—CAA Spec. L-819, HRL fixtures (33,500 c.p. maximum)
Setting—No. 5, 100 per cent intensity
Approach lights—neon bar, CAA Spec. 227 (900 c.p. maximum) at full intensity

Vertical Contact

Fig. 4 illustrates the cumulative probability curve for obtaining vertical contact based upon the conditions previously described. In inspecting this figure, it may be seen that the probability is approximately 0.90 that the pilot will have obtained visual reference with the ground in a vertical direction at or before he reaches a height of 390 ft. above the runway. He has a probability of 0.50 of obtaining vertical contact before he reaches a height of 470 ft. above the runway. The probability is 0.90 that the pilot will obtain vertical contact between the limits of 610 and 380 ft.

Approach Light Contact

Fig. 5 illustrates the cumulative probability of the pilot's obtaining visual reference with the outermost light of the neon bar approach light system. In this case at MacArthur Field, this light was located 1,358 ft. from the runway threshold. It may be seen that more narrow limits exist for this case than existed for vertical contact. A 0.90 probability exists that the pilot will obtain visual reference with the neon bar approach light between a height of 300 and 213 ft. The most likely height for contact will be 250 ft.

Runway Threshold Contact

The case of the runway threshold contact is more complicated than the prior two cases, since several means of visual recognition are possible in this case. The pilot may first see the threshold lights, he may see runway markings against the runway itself, or he may see the runway against its surrounding terrain. Fig. 6 illustrates the probability curves for obtaining runway threshold contact either on runway threshold lights that are at maximum intensity or on modified Calvert markings as existed at MacArthur Field. It is to be noted that for a probability of 0.90 the range of variation in threshold contact heights is approximately the same for both cases—namely, 75 ft. However, the probability of 0.95 exists that the pilot will see the runway threshold lights at or before a height of 226 ft., whereas in the case of the runway markings the same probability exists for a height of 96 ft. This is, of course, a striking example of the effectiveness of lights under this particular type of weather condition. A word of caution is warranted at this point in that this figure should not be used to draw general conclusions as to the effectiveness of lights since, under some conditions of low visibility and high ambient light, exactly the reverse situation may occur.

Runway Visual Range

Fig. 7 illustrates the variation in runway visual range for high-intensity runway lights of 33,500 c.p. as opposed to runway visual markers of the British pup-tent type. An even more striking variation in visual range is apparent in this case than in the threshold contact situation. However, here again under conditions of extremely low visibility, the position of the two curves may be transposed, and visual range on markers or markings on the runway surface could be greater than that possible with high-intensity runway lights.

The preceding figures illustrate the results of the flight-test program with respect to one specific set of meteorological and photometric conditions. As a part of the analysis of the results, generalized charts were

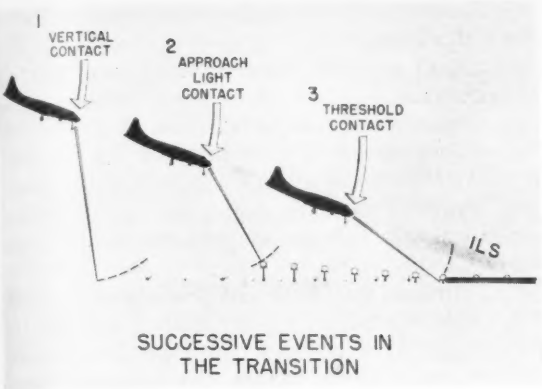


FIG. 1.

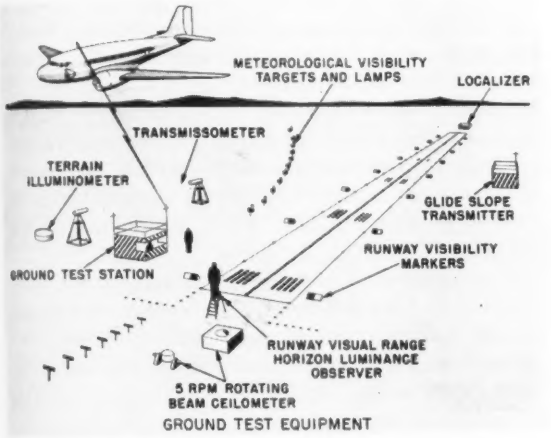


FIG. 2.

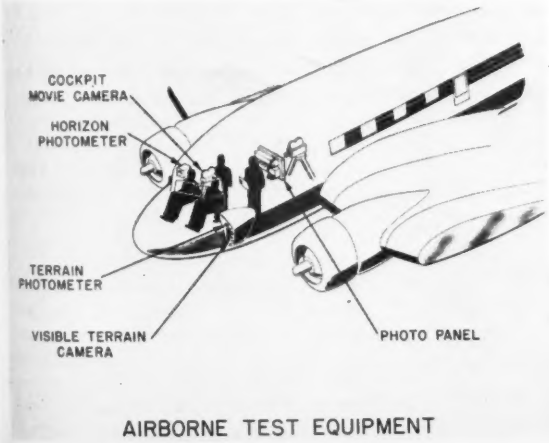
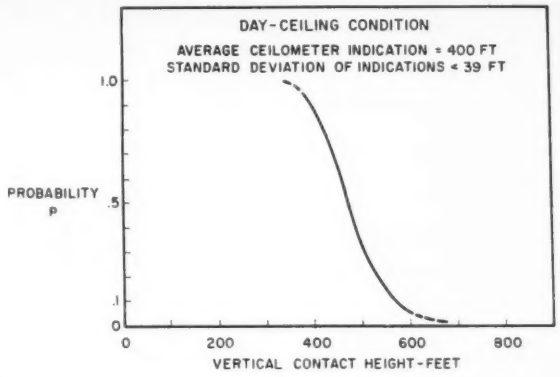
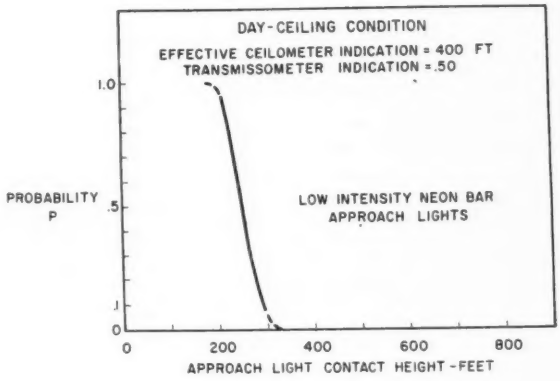


FIG. 3.



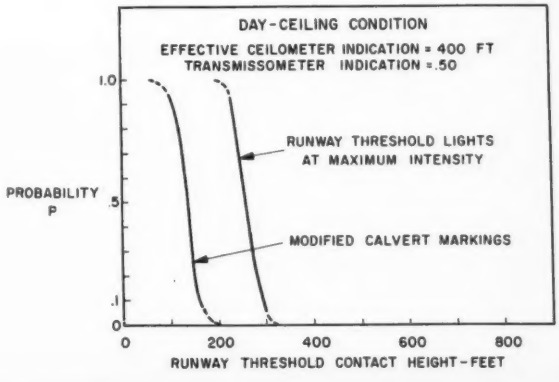
PROBABILITY OF PILOT OBTAINING VERTICAL CONTACT

FIG. 4.



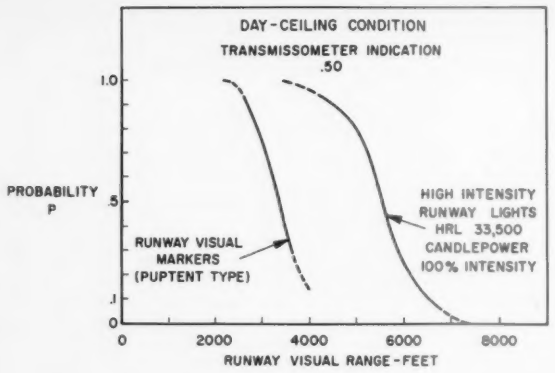
PROBABILITY OF PILOT OBTAINING APPROACH LIGHT CONTACT

FIG. 5.



PROBABILITY OF PILOT OBTAINING RUNWAY THRESHOLD CONTACT

FIG. 6.



PROBABILITY DISTRIBUTION FOR RUNWAY VISUAL RANGE

FIG. 7.

constructed which covered ranges of ceilometer and transmissometer indications and photometric values. Series of charts were constructed for each of the three weather classifications of ceiling, radiation fog, and snow.

The application of this more general form of weather measuring shows great promise in eliminating the past objections to weather reporting. This is true because the system takes into account parameters, not formerly considered, which greatly affect what the pilot can see from the cockpit. With this system, an approach weather report can describe the weather in more realistic terms to the pilot. For example, a predicted vertical contact, approach light contact, runway threshold contact, and runway visual range could be supplied to the approaching aircraft.

THE CONCLUSIONS

(1) As a result of this evaluation program it is concluded that the transmissometer and rotating beam ceilometer combination provide a sound method for remotely measuring weather in the runway approach zone.

(2) Supplementary photometric data are required for the optimum interpretation of these weather observations in terms of what the pilot will see from the cockpit. These supplementary photometric data consist of the following:

(a) Terrain illuminance measured with a foot-candle meter.

(b) Horizon luminance in the landing direction measured with a photometer.

(c) Airport approach, threshold, and runway lighting configuration.

(d) Airport terrain reflectance factors.

(3) Determination of what the pilot will see from the cockpit under the weather and photometric conditions measured with the ceilometer-transmissometer system can only be expressed as a function of probability.

(4) To receive the full benefit of this weather measuring system the manner in which weather is reported to the pilot should be modified. An expanded approach weather report could include the following items: vertical contact height, approach light contact height, threshold contact height, and runway visual range.

THE FUTURE

The 1953–1954 ANDB program has led to conclusions concerning the manner in which the ceilometer-transmissometer system can be used for improving approach zone weather reporting. It is anticipated that the results of this work can be applied operationally at those airports where the Weather Bureau is making field installations of the equipment. It appears likely that in the near future an extended field program to evaluate the ceilometer-transmissometer weather measuring system will be instituted at Newark Airport under the sponsorship of the ANDB. Funds for the project will be supplied by the U.S. Air Force.

In this program the generalized results of the MacArthur Field tests will be used in conjunction with the Newark approach and runway lighting system. An approach weather report based upon the expanded weather data will be given to the air-line pilot making his instrument approach. Observations of the air-line pilot himself, while on the approach, will be used to document the accuracy of the system. When implemented, the program will include as operating test personnel the air-line pilot himself, the Weather Bureau, the CAA, and the Sperry Gyroscope Company. The proposed Newark program has been designed to record in a systematic manner the air-line pilot's utilization of the proposed approach zone weather reports and to determine if the results anticipated by the 1953–1954 ANDB program are substantiated under actual air-line operation conditions.

Northeastern Student Conference

(*Continued from page 52*)

ceeded to define "cruise control" as the technique of flying to obtain fuel efficiency for a type of mission specified. He also said that an invariant parameter is one that remains approximately constant during maximum-range cruise. For example, Mach Number remains approximately constant during optimum cruise. In the remainder of his talk, he explained that in actual application the instrumentation of these parameters would automatically pilot the plane during the maximum-range cruise.

The next graduate speaker was John Zvara of M.I.T., whose paper was entitled "Matrix Method for Determining the Aileron Effectiveness of an Elastic Swept Wing of Arbitrary Plan Form and Stiffness." In his talk, he set up the integral equation for torsional static equilibrium for a swept wing and indicated a numerical solution of matrix form. He also brought out how poor a swept wing is from the standpoint of aileron effectiveness.

The last paper, by Eugene Mark Romer and Luciano L. Mazzola, both graduates of M.I.T., was presented by Romer. The title was "An Investigation of the Aerodynamic Characteristics of a Combined Swept-Back-Swept-Forward Wing Configuration."

At the completion of the presentation of the student papers, the visitors were given a description of the course of study for bachelors', masters', and doctorate degrees at Brooklyn Poly by Prof. Martin Bloom. Professor Bloom mentioned that there has just been an extensive change in the undergraduate curriculum to include, among other things, an early introductory course in aerodynamics for sophomores, more credits of theoretical aerodynamics and a more complete study of compressible flow with heat addition in connection with power plants.

After this, Paul A. Libby gave a talk on the Brooklyn Poly research facilities for high-speed aerodynamics at Freeport, L.I. The idea of the talk was to give the visitors some background information for their tour of the laboratory the following day.

After Libby's speech, the whole group went to a smoker where refreshments were served and a film on the Flying Display and Exhibition at Farnborough, England, was shown.

On Saturday morning, the group visited the Supersonic Aerodynamics Laboratory in Freeport. The facility boasts of three supersonic blowdown wind tunnels. Paul A. Libby and Mike Visich of the Freeport staff explained the operation of the equipment to the students. Most impressive of the equipment was the preheated hypersonic tunnel capable of Mach 10 with full-scale conditions.

Saturday evening, an awards banquet was held at Henri Ferrar's in Brooklyn. Present at the dinner were the visiting students; Professors Hoff, Kempner, Libby and Bloom; Thomas Meskel, IAS Assistant Secretary; and guest speaker Richard W. Porter. Porter, President of the American Rocket Society, is presently a Consultant—Communication and Control, Engineering Services Division, General Electric Company. Until recently, he was General Manager of G-E's Guided Missile Department. His talk was mainly concerned with the use of guided missiles in warfare, but he also spoke about some applications of the rocket engine for peacetime use.

After Porter's speech, Nicholas J. Hoff awarded the prizes for the winning papers. The money for these awards is part of the Minta Martin Aeronautical Student Fund. For undergraduates, the first award of $100 was won by Roger Barron and Huston Landis for their joint paper on the canard. The second award of $75 was won by Frank Schlee for his paper on strain gages, and the third award of $50 was given to Forman Williams for his paper on wind-tunnel calibrations.

The $100 first award in graduate papers went to John Zvara for his paper on aileron effectiveness of swept wings. The second prize of $75 went to Eugene Romer and Luciano L. Mazzola for their study of the combined swept-back-swept-forward wing. Third award of $50 went to Earl W. Erickson for his paper on cruise control. Each winner also received an engraved merit certificate.

The awards presentation brought the conference to a close. As a parting note, Brooklyn Poly's IAS Branch officers—Louis Divone, Chairman; Anthony Martellucci, Vice-Chairman; Ernest Riesenfeld, Treasurer; J. Richard Nelson, Corresponding Secretary; and Murray Rosenberg, Recording Secretary—extended congratulations to the winners and expressed the hope that all would be present at next year's conference.

MURRAY ROSENBERG
Recording Secretary
IAS Student Branch
Polytechnic Institute of Brooklyn

Attention Members!

All members of the Institute are invited to submit material concerning their activities for publication in the "News of Members" columns of the *Aeronautical Engineering Review*.

IAS News

(*Continued from page 53*)

American Wheelabrator & Equipment Corporation.

▸ **Austin Wickwire** (M), Engineering Representative—San Diego, Lockheed Aircraft Corporation, is now responsible for the engineering activities on all Lockheed models in the San Diego area.

Members on the Move

The purpose of this section is to provide information concerning the latest affiliations of IAS members. All members are therefore urged to notify the News Editor of changes as soon as they occur.

Warren V. Boughton (AF), Chief Electrical Engineer, Republic Aviation Corporation. Formerly, Vice-President and General Manager, Phaostron Company.

Raymond F. Crisp (M), President and General Manager, Associated Missile Products Corporation, Pomona, Calif. Formerly, Manager, Technical Services, Hycon Manufacturing Company.

Anthony F. Dernbach (TM), Development Engineer in charge of a special propeller program, Hamilton Standard Division, United Aircraft Corporation. Formerly, Senior Project Engineer, Hamilton Standard.

Walter H. Dickman (AM), now Vice-President—Sales and Engineering, Harley Patents, Inc.

Victor Di Cristina (TM), Technical Engineer, Small Aircraft Engine Division, General Electric Company. Formerly, Research Engineer, North American Aviation, Inc.

Samuel E. Eastman (AM), with Logistics Section, The RAND Corporation. Formerly, Assistant Professor of Business Administration, Graduate School of Business Administration, Harvard University.

Laurence E. Fogarty (AF), Chief Engineer, Link Aviation, Inc. Formerly, Project Engineer, T-37A and E-600 Projects, Link.

Isaac Greber (TM), with Department of Aeronautical Engineering, Massachusetts Institute of Technology. Formerly, Senior Aerodynamics Design Engineer, Chance Vought Aircraft, Incorporated.

Marion S. Israel (M), Field Consultant, D. D. Pettit Company, Consultants. Formerly, Senior Engineer, Preliminary Design, North American Aviation, Inc.

William E. Laundry (TM), with Engineering Division, The de Havilland Aircraft of Canada, Ltd. Formerly, with Division of Mechanical Engineering, National Research Council, Canada.

John C. McGinnis (TM), Associate Engineer, P.D. Stress Unit, Boeing Airplane Company, Seattle. Formerly, Junior Engineer "A"—Stress Analyst, Boeing, Wichita.

Carl S. Newman (M), Owner, Special Machinery, 132 Nassau St., New York 38, N.Y. Formerly, Project Engineer, Control Electronics Company, Inc.

Dunstan Graham, MIAS, has been appointed Department Head of Flight Control Systems of the Grand Rapids Division of Lear, Incorporated. He was formerly Chief of the All-Weather Section, Directorate of Flight and All-Weather Testing, WADC.

Charles J. Newman (TM), Junior Engineer, Structures Section, Convair, Fort Worth, a Division of General Dynamics Corporation. Formerly, Airborne Radio Mechanic, USAF.

H. Erich Nietsch (M), Vice-President, Project Development, Robinson Aviation, Inc. Formerly, Assistant to the President and Manager—Industrial Division, Robinson Aviation.

Robert F. Robinson (M), with Headquarters, Air Research and Development Command, USAF. Formerly, Associate Professor of Aeronautical Engineering, USAF Institute of Technology.

Albert O. Schmitt (AM), Manager, Philadelphia Sales Office, Aero Engineering Company, The Garrett Corporation, 76 Rittenhouse Place, Ardmore, Pa. Formerly, Installation Engineer, Aero Engineering.

Martin J. Poggi, MIAS, has been named District Manager of Cook Electric Company's recently opened Northwest district office in Seattle. Prior to this appointment, Mr. Poggi was Installation Engineer, Airsupply Company, Division of The Garrett Corporation.

Sheldon P. Smith (M), Head, Charlotte (N.C.) Division, Douglas Aircraft Company, Inc. Formerly, Assistant Chief Missiles Project Engineer, Santa Monica Division, Douglas.

Albert A. Werth (M), Senior Proje Engineer, Allison Division, General M tors Corporation. Formerly, Prelimina Design Engineer, Fairchild Aircraft Div sion, Fairchild Engine and Airplane Cor

Corporate Member News

• **Aluminum Company of America. . .**Two new aluminum welded tube mills have been placed in production at the company's Alcoa, Tenn., works. They are capable of producing welded aluminum tube and pipe from 1/2 in. to 8 in. in diameter.

• **Bendix Aviation Corporation. . .**The Utica Division has opened a new $100,000 facility for engineering, sales, and servicing of its products. It is located in North Hollywood, Calif., adjacent to the headquarters of the Bendix Pacific Division at 11600 Sherman Way, and is under the supervision of Edwin O. Cooper, MIAS, Manager of West Coast sales and service.

• **Convair, a Division of General Dynamics Corporation. . .**A ballistics method for studying the destructive effect of rain on aircraft and missiles flying at supersonic speed has been developed at the Convair, San Diego, plant. Test specimens of metals, plastics, or ceramics are fired from a 20-mm. aircraft cannon at speeds up to 1,900 m.p.h. (Mach 2.5) through a water spray simulating rainfall. The specimens are recovered by means of small parachutes and examined for rain erosion. Convair is conducting the project for the Materials Laboratory of the Wright Air Development Center.

• **Curtiss-Wright Corporation. . .**A new type of turboprop power plant, called by Curtiss-Wright the De-Rated Turboprop engine, was recently announced. According to company engineers, the weight-to-power ratio of the De-Rated Turboprop will be 65 per cent better than any engine now in commercial use. Studies indicate that this power plant can make it possible—both mechanically and economically—for the air lines of the world to fly across the U.S.A. in 5½ hours and across the North Atlantic in 7½ hours. Proposals to incorporate the De-Rated Turboprop in either present-day or forthcoming air liners have already been made by Curtiss-Wright to transport-aircraft producers in the United States and to air-line executives both in this country and abroad.

• **Douglas Aircraft Company, Inc. . . .**A new division, to be known as the Charlotte Division, is being established at Charlotte, N.C., to serve as a secondary source to the Santa Monica Division in the production of the Nike guided missile. This new factory is being set up in the 1,250,000-sq.ft. plant formerly operated as the Charlotte Quartermaster Depot. The building is being rehabilitated by the U.S. Army Corps of Engineers and will be occupied by Douglas in June or July of this year. Actual production at the Charlotte Division is expected to begin early in 1956. Heading the new division will be Sheldon P. Smith, MIAS, formerly Assistant Chief Missiles Project Engineer at Douglas, Santa Monica. . . .A newly manufactured RB-66 reconnaissance bomber landed earl in February at Tucson Municipal Airpo and so initiated the new Douglas Tucso facility as a production test base. A undisclosed number of B-66 aircraft are t be modified and flight tested at the Tucson plant prior to delivery to the Tactical Air Command. This facility, operated by the company's Long Beach Division, adjoins the Tucson airport.

• **Douglas Aircraft Company, Inc., and Convair, a Division of General Dynamics Corporation. . .**The sum of $2,200,000 was allocated by the U.S. Air Force for the expansion of testing facilities at Edwards AFB, Calif. These flight test facilities, which will be shared by Douglas and Convair, will be ready for occupancy by late summer.

• **Fairchild Camera and Instrument Corporation. . .**A building with some 24,000 sq.ft. of floor space is now being constructed on a 6-acre site in Los Angeles and is scheduled for completion in June. There will be adequate space for an additional 24,000 sq.ft. to be built at a later date. This new West Coast plant will be set up primarily to house the expanded manufacturing facilities of the Fairchild Potentiometer Division; however, it will also include office facilities for the other divisions and subsidiaries concerned with aerial cameras, graphic arts products, and portable power tools. . . .It was recently announced that, effective March 1, 1955, Fairchild Aerial Surveys, Inc., became a wholly owned and operated subsidiary of Fairchild Camera and Instrument Corporation. Fairchild Aerial Surveys, founded in 1924, had been operating since August 13, 1936, under a voting trust agreement as a partially owned subsidiary of the parent corporation. This subsidiary company has offices in Los Angeles, Long Island City, and Manhattan.

• **General Electric Company. . .**The Instrument Department is producing compass-controlled directional gyro compass systems for the U.S. Navy. These G-E compass systems, Type MA-1, have a reported free gyro drift rate of less than 4° per hour and are planned for use in Naval fighters, attack planes, and submarine-hunting helicopters. . . .A six-point jet-engine service program is described in detail in G-E's new 16-page bulletin titled "Operation Service" and designated GEA-6136. The program described therein was set up by G-E to help engine users cut operating costs and obtain top performance from the G-E J-47 and J-73 engines. Bulletin GEA-6136 is available from the company's Schenectady, N.Y., office.

• **Jack & Heintz, Inc. . . .**Two new relays have been developed to meet the problems of switching the high currents encountered in aircraft 28-volt d.c. systems. Designed to meet all requirements of Specification

FIRST die forging press in the Air Force Heavy Press Program — 35,000-ton capacity. Now in operation and capable of producing forgings larger than heretofore attempted. Again, as from the beginning of the aviation age, Wyman-Gordon pioneers in scientific advance.

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Amphibious floats have been developed by Edo Corporation for aircraft in the Cessna 180 class. These floats, Model 289, are designed with a quadricycle landing gear that is retracted and extended by means of an electromechanical actuating system housed in each float. The two main wheels, located just aft of the step, retract into wheel wells for water landings. The full castering nose wheels retract upward for water landings so that the struts are flush with the forward section of the keel and the wheels are exposed just forward of and below the bow bumpers. The control and position-light system has been designed to fit into any standard instrument cutout.

MIL-R-6061, these single-pole, single-throw relays are identical except for mounting. The JH28007-1 relay conforms to an AN3370-1 mounting while relay JH28007-2 meets an AN3370-2 mounting. The relays weigh 1.25 lbs.

• **Lear, Incorporated.** . .A three-phase plant-expansion building program has been completed. This includes the construction of additional facilities for all five divisions. New construction during the past year totaled 198,600 sq.ft., bringing Lear's total plant facilities to 536,100 sq.ft.

• **Lockheed Aircraft Corporation.** . .The one-hundred-millionth man-hour of work on Constellation series airplanes was celebrated on February 21.

• **Pratt & Whitney Aircraft Division, United Aircraft Corporation.** . .The one-thousandth J-57 turbojet engine has been shipped, the company announced on March 8. The J-57 has been in volume production since February, 1953.

• **Simmonds Aerocessories, Inc.** . . .A new type of explosion suppression system has completed an intensive program of laboratory and flight tests and is being installed on production models of the Chance Vought F7U-3 Cutlass. This device, known as the Simmonds Explosion and Fire Suppression System, has two basic components—a sensing element or detector and one or more capsules or small reservoirs to which the detector is connected electrically. In operation, the detector senses an incipient hazard and in microseconds triggers the system, the capsule which is ruptured by means of a detonator releases a suppressant mist and snuffs out the potential danger while relatively harmless. The F7U-3 installation of this system includes protection for leading edge cavities and fuel cells. The original research which led to the invention of the Explosion and Fire Suppression System was done prior to 1950 at the Royal Aircraft Establishment in England. This particular system was developed and manufactured in this country by Simmonds under license from the English inventors.

• **Solar Aircraft Company.** . .The new Model T-300J gas-turbine-driven ground power units, now in production for the Air Force, are expected to supply enough compressed air under all operating conditions to start such large jet engines as the Allison J-71 and Pratt & Whitney J-57. This portable unit was developed from a 500-hp. Jupiter gas-turbine engine that was modified so that most of its output would appear in the form of compressed air bled from the gas turbine's compressor. The Jupiter was originally developed under a USN contract as a prime mover for electric generators and high-speed boats.

• **Stanley Aviation Corporation.** . .A Stanley T-33A cockpit procedure trainer has been installed at Laredo AFB, Tex., for evaluation. In addition to normal training in operation of the T-33, the student can be subjected to flame-outs, fire, hydraulic failures, etc., and his responses can be observed. The trainer is intended to introduce the pilot to alien and/or complex equipment or situations, thus reducing accident potential. A procedure trainer prototype for the F-84F has been tested at Luke AFB, Ariz.

• **Thompson Products, Inc.** . . .An American Legion annual award was presented to Thompson for its employment of physically handicapped veterans. Employment figures for two Thompson plants show that the company had 325 physically handicapped veterans out of a total of 9,762 male employees, including 2,750 veterans.

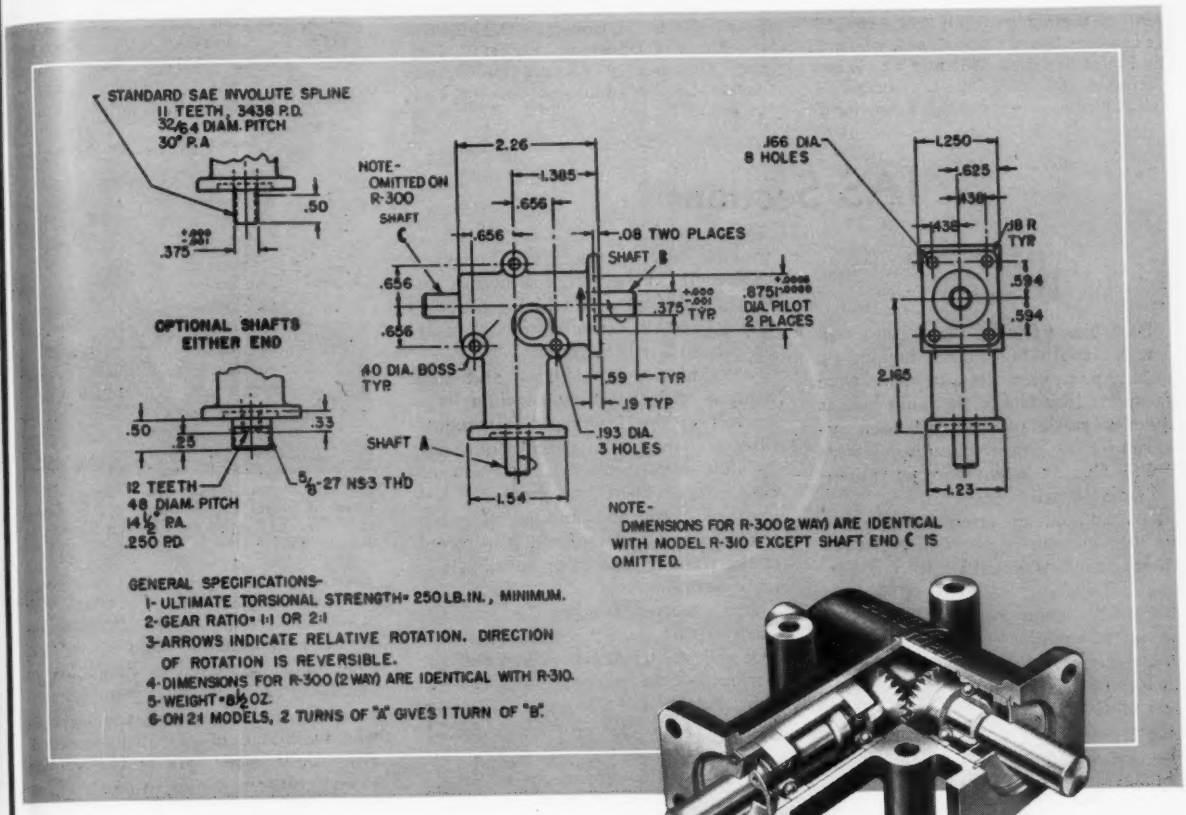
• **Union Carbide and Carbon Corporation.** . .A new technical booklet on isopropanol has been released by Carbide and Carbon Chemicals Company, a U.C.C. Division. This 16-page publication contains information on the uses, physical and physiological properties, shipping data, specifications, and constant-boiling mixtures of isopropanol. The booklet (F-8731) is available from any of Carbide's offices and from Carbide and Carbon Chemicals' New York office. . . .Two new Vice-Presidents of Linde Air Products Company, a U.C.C. Division, were recently announced. They are Eugene Easterly, Vice-President—Distribution; and E. G. Hickling, Vice-President—Operations.

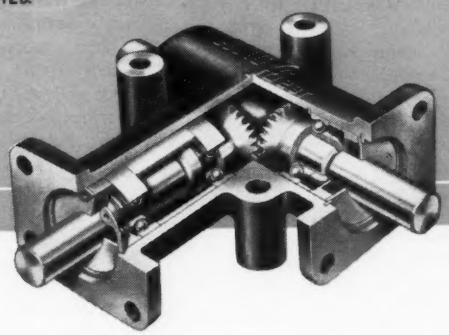
• **United Air Lines, Inc.** . . .The new $6,000,000 hangar and operations building at New York International Airport (Idlewild), which is scheduled for occupancy this month, is reportedly the largest air-line facility at that field. This structure, constructed of brick and steel, covers $4\frac{1}{2}$ acres of a 43-acre track. Ramp area, parking space, and future buildings will take up 30 acres. The hangar has almost 65,000 sq.ft. of floor space, and the office area has some 35,000 sq.ft. of floor space. The land on which this new structure is located has been leased from the Port of New York Authority for 20 years, with an option for renewal at the end of that time. . . .Aksel Nielsen, a Colorado financier who is a Past-President of the Mortgage Bankers Association of America, has been elected to the U.A.L. Board of Directors. This action increases the Board's membership to 13.

• **Western Gear Works.** . .A hand-operated air-borne type of hoist has been designed to provide for a maximum operating load of 1,000 lbs. with a reeling capacity of 22 ft. of 3/32 cable. It is said to be capable of being driven with a standard 3/8 hex socket speed wrench. The ratio is five turns of the input for one revolution of the drum, providing a maximum pull-off angle of 12°. The installed weight is 4.75 lbs.

• **Westinghouse Electric Corporation.** . . The Electronics Division has announced plans to build a plant near Friendship Airport, Baltimore, for production of military electronic equipment. It will be adjacent to the Westinghouse Air Arm Division plant. Scheduled for occupancy in January, 1956, the plant will have 210,000 sq. ft. devoted to manufacturing space and 140,000 sq.ft. for engineering and office facilities. . . .A 31-page booklet (B-6392) on air-borne electrical power is available from the Pittsburgh office. This publication emphasizes, through illustrations and test material, the extensive facilities available and necessary for developing, producing, and testing aircraft electrical systems and components.

• **Wyman-Gordon Company.** . .A 35,000-ton closed-die forging press has been placed in operation as part of the USAF heavy press program. First forgings produced—the largest light-alloy forgings ever made—were aluminum wing spars for the Convair F-102. The spars were 12 ft. long, 18 in. wide at the widest point, and as little as 3/16 in. thick in some areas. Four such spar forgings in the F-102 will replace 272 parts and save 3,200 rivets per plane, cutting the weight of the plane by 100 lbs. The giant hydraulic press was designed by Loewy Construction Company, Inc., subsidiary of Hydropress, Inc. A 50,000-ton press is being assembled by Loewy at the same plant for operation in the late summer. . . .Robert W. Stoddard, formerly Vice-President, was named Pres-





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R-300 2-way	1:1	⅓	1800	450	⅜	½
R-300-2 2-way	2:1	⅓	1800	450	⅜	½
R-310 3-way	1:1	⅓	1800	450	⅜	½
R-310-2 3-way	2:1	⅓	1800	450	⅜	½
R-320 2-way	1:1	1	1800	1500	⅜	2.2
R-320-2 2-way	2:1	1	1800	1500	⅜	2.2
R-330 3-way	1:1	1	1800	1500	⅜	2.4
R-330-2 3-way	2:1	1	1800	1500	⅜	2.4

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ident of the company on February 23. He succeeds Harry G. Stoddard, who held the Presidency since 1931 and who is now Chairman of the Board. George F. Fuller, an employee of the company for 67 years, was made Honorary Chairman of the Board of Directors. Sacket R. Duryee, Treasurer of Wyman-Gordon, was named to the additional post of Vice-President.

IAS Sections

Chicago Section

Leland W. Sims, *Secretary*

The Chicago Section met at the Glenview Naval Air Station on January 19. At 6:30 p.m., members and guests were transported by bus to the main hangar where a static exhibit had been arranged for the group. On display were an F9F Cougar, a two-place jet trainer, and an HUP helicopter.

At 7:30 p.m., the group assembled in the dining room of the Officers' Club where dinner was served to 110 persons. Following dinner, Chairman Richard A. Schram opened the meeting and introduced the guests: Rear Adm. Daniel V. Gallery, USN, Chief of Naval Air Reserve Training, and Mrs. Gallery; Carl Stockholm, President of the Navy League of Chicago, and Mrs. Stockholm; Mrs. Richard A. Schram; Capt. W. R. Hollingsworth, USN, Commanding Officer, NAS Glenview, and Mrs. Hollingsworth; Comdr. H. Vincent, USN, Executive Officer, NAS Glenview; and Kenneth L. Burroughs, President of The Aeronautical University and Chairman of the Chicago Section Advisory Board.

Mr. Schram then introduced the guest speaker, Vice Adm. Austin K. Doyle, USN, Chief of Naval Air Training. Admiral Doyle spoke on the function and requirements of aircraft used in the Navy training programs. He stressed the need for safe and reliable aircraft in training Navy pilots. He emphasized that there was a need for aircraft designed specifically for training purposes and decried the common practice of using second-line fleet aircraft.

Admiral Doyle used a statistical analysis of fleet-type and training-type aircraft in the Training Command to illustrate their comparative qualities. In all aspects compared, such as accident rate, accident cost, number of aircraft required, and number of maintenance personnel required, the record of the training-type airplane was strikingly favorable.

It is a matter of record that training-type aircraft have been designed and procured which will match favorably the performance of combat craft with increased safety and economy. However, Admiral Doyle stressed the need for additional work on the design of a two-place swept-wing trainer for use in the near future. Also desired is a multi-engined trainer to prepare pilots for the aircraft now in production for fleet use. Admiral Doyle concluded by urging airplane designers to keep in mind the difficulties involved in training young men to fly combat aircraft now in production.

Vice Adm. Austin K. Doyle, USN, Chief of Naval Air Training, NAS, Pensacola, Fla., addressed the Chicago Section on January 19.

▶ On February 2, the Chicago Section met at 6:00 p.m. in the Dehmel training room of United Air Lines, Inc. Seventy-four persons were conducted through two Dehmel flight simulators—a DC-6 and a Convair—where operators demonstrated how flight crews are given experience in handling flight situations, some of which would be impossible to simulate in actual flight. John Sandow, Head of UAL's Dehmel training unit, was in charge of the demonstration. Groups alternated between the training room and the adjoining cafeteria, where dinner was served.

At 8:00 p.m., 105 members and guests assembled in the auditorium of the main building of United Air Lines, where the Cockpit Procedures Panel was held. The panel included Richard C. Dehmel, Chief Engineer, Electronics Division, Curtiss-Wright Corporation; I. E. Sommermeyer, Director of Flying, UAL; Carl Christenson, Director of Safety, UAL; and Capt. Lawrence Shapiro, UAL. Richard A. Schram, Section Chairman, opened the meeting and introduced the speakers.

Mr. Dehmel described in considerable detail the complexities of the training units he had designed. He pointed out the function of each part in conjunction with the electronic computer in simulating the control, instrument, and flight responses so that the trainer responds in an identical manner to the actual airplane in flight.

Mr. Sommermeyer discussed the introduction of good cockpit procedures into air-line operation and stressed the need for experience in gaining this. He emphasized that this experience should be gained by use of training devices. He traced the development of cockpit procedure for air crews from the time of the first multiengined airplane to its present status with the armed forces and the air lines. During this period came the gradually increasing need for and application of training devices.

Mr. Christenson spoke on safety aspects of air-line operation and concurred with Mr. Sommermeyer on the

Inspecting United Air Lines' Dehmel Flight Simulator at the February 2 meeting of the Chicago Section are *(left to right)*: Alfred F. Stott, Dean of Engineering, The Aeronautical University; Gus Sommermeyer, Director of Flying, UAL; and George Ferguson, Dehmel Instructor, UAL.

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advantages of flight simulators in training crews in good cockpit procedures. He emphasized the remarkable safety record of commercial air travel but stressed the desire of all air lines to perfect their safety records further. The flight simulator was described as a necessary aid in attaining this goal.

Captain Shapiro spoke on the pilot, the airplane, and safety. In stressing the importance of a device such as the Dehmel trainer, he described the pilot-machine relationship and the maintenance of proper balance of this relationship. He discussed environmental influence, pilot capability, workload, crew capacity, and the factors that influence a pilot or crew workload capacity. He concluded by illustrating the manner in which training, safety, education, and improved aids are used to maintain the proper balance of pilot, airplane, and environmental influence.

▶ On Wednesday, March 2, the Chicago Section met at the Museum of Science and Industry for its annual student meeting. Continuing the policy of the previous 4 years, the Student Members in the Chicago area arranged and conducted a symposium-type program. The theme of the symposium this year was "Techniques for Testing Airplanes and Men."

At 6:30 p.m., 68 members and guests assembled in the cafeteria of the Museum of Science and Industry for dinner. Later in the evening 107 members and guests met in the auditorium of the museum. The meeting was opened by the Chicago Section Chairman, Richard A. Schram. Mr. Schram introduced the Chairman of the Student Affairs Committee, Alfred F. Stott, who described the manner in which the students, in conjunction with the committee, planned the program. Mr. Stott then introduced Philip Meyer, a junior in aeronautical engineering at the University of Illinois in Champaign, who was selected to be Chairman for the evening. Mr. Meyer thanked the Chicago Section for turning over one of its regular meetings to the Student Members and expressed the sentiments of all Student Members in hoping that this would be continued in future years.

The first speaker, Stanley A. LaFavor, Group Stress Engineer, McDonnell Aircraft Corporation, was introduced by Student Member Raymond Richardson, of the University of Illinois in Chicago. Mr. LaFavor's paper was entitled "Test Development of Structures Designed Understrength." He described in considerable detail the stretch-test procedure used in design at McDonnell Aircraft, illustrating with slides the method of static testing to failure and redesign of the weakest parts so that the lightest possible final structure is attained. This also illustrated

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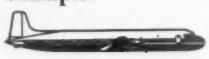
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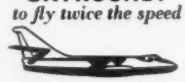
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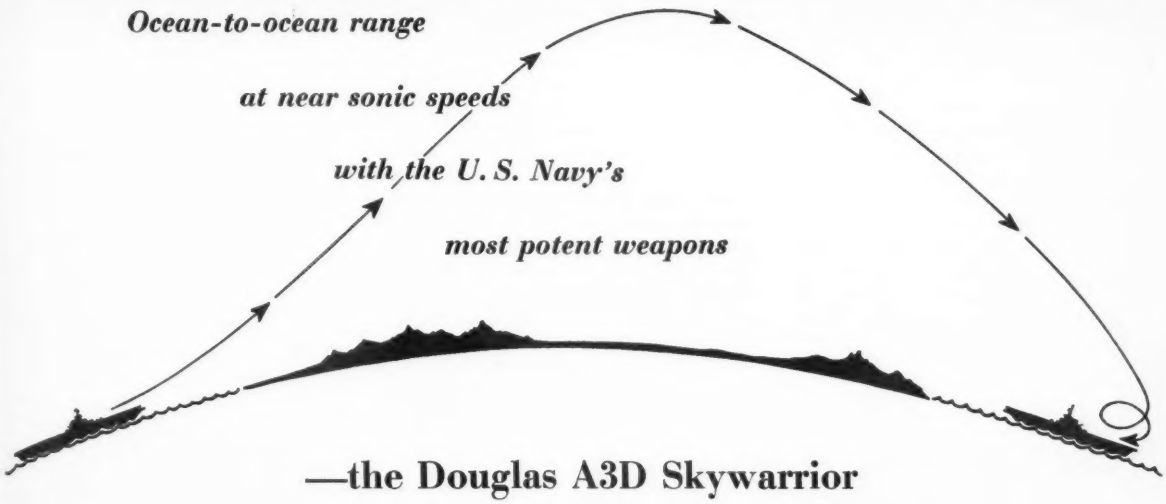

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the necessity of incorporating static testing with the design department.

The second scheduled speaker, James A. Coleman, Engineering Test Pilot, Convair Division of General Dynamics Corporation, was unable to appear at the meeting to present his paper because of flight-test-schedule complications. Mr. Coleman was to have been introduced by Student Member Robert W. Yeager, of The Aeronautical University.

The final speaker was Capt. Julius C. Early, USN (MC), Commanding Officer of the U.S. Naval School of Aviation Medicine, Pensacola, Fla. Captain Early was introduced by Student Member Kenneth Hudson, of the Illinois Institute of Technology.

Captain Early traced thoroughly the testing procedures used by the Navy from the initial selection of pilot candidates to the final testing of qualified pilots to determine their ability to withstand high-inertia forces encountered in all maneuvers and speeds. Altitude tests in low-pressure chambers were also described; these chambers are used to determine the individual's limitations and reactions caused by deficient oxygen supply.

The two speakers held a question-and-answer period at the end of the program and were generous in extending this period to the satisfaction of all present.

Mr. Schram closed the program with thanks to the speakers, the students, and the Student Committee. The meeting was adjourned at 10:45 p.m.

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Cleveland-Akron Section

Howard F. Powders, *Secretary*

The February 24 meeting of the Cleveland-Akron Section was held in Akron jointly with the American Rocket Society. The guest speaker on this occasion was Walter R. Dornberger, Guided Missile Consultant to the Bell Aircraft Corporation, who will be remembered for his rocket research work in Germany and particularly for the development of the V-2 missile.

Speaking on "The Rocket-Powered Commercial Air Liner," Dornberger discussed all the operational problems that would be encountered, including high speeds, types of fuel, and flight scheduling. He made numerous comparisons between his projected rocket air liner and present-day transport aircraft. His talk was illustrated with slides presenting the operational problems in graphic form. Other slides showed his conception of what the future rocket-powered air liner would look like in flight and at its take-off and landing stations.

Following this presentation, the meeting was held open for a question-and-answer period. All members of the committee agreed that this was one of the most interesting meetings our section has had in recent months.

Dayton Section

Gunther R. Graetzer, *Secretary*

On February 24, the Dayton Section held a dinner meeting at the Engineers Club. Eighty-four members and guests were present for the dinner.

At the beginning of the evening's program, the Honorary Chairman, Rear Adm. T. C. Lonnquest, and the Chairman, George J. McTigue, introduced the guests of honor. These included: S. Paul Johnston, Director of the IAS; R. R. Dexter, IAS Secretary; and Brig. Gen. Harold E. Watson, USAF, speaker of the evening. General Watson, Commander, Air Technical Intelligence Center, discussed "Soviet Air Technical Achievements." (The text of General Watson's address will appear in the June issue of the REVIEW.)

A movie of the Soviet military power exhibited during the May, 1954, Moscow Festival concluded the evening, the most outstanding of the 1954–1955 session.

General Watson's address attracted a record attendance of 166 members and guests.

Hagerstown Section

Andrew Pickens
Secretary-Treasurer

Three executives of Fairchild Aircraft Division, Fairchild Engine and Airplane Corporation, spoke at the February 15 meeting of the Hagerstown Section. W. R. Long introduced the speakers: S. T. Mulroney, Manager of the Materials Department; C. M. Gehlhaus, General Supervisor of Material Control; and C. F. Murray, Purchasing Agent. Thirty-five members and guests attended.

A report on the annual IAS chairmen's meeting, held in New York on January 25, was presented by Theodore H. Beck. He described the efforts being made by other Sections to promote interest in engineering among high school students. He said that educational leaders in the Hagerstown area would be contacted to arrange for talks to be given by IAS members at school gatherings.

Los Angeles Section

Joseph W. Wechsler, *Secretary*

In a talk entitled "My Reactions to Current Design Trends" delivered at the February 17 dinner meeting, Anthony W. Le Vier, Chief Engineering Test Pilot, Lockheed Aircraft Corporation, provided 450 members and guests of the Los Angeles Section with an entertaining evening as well as with considerable food for thought. Mr. Le Vier's address offered a worth-while list of recommendations for the consideration of airplane designers.

A significant point made by the speaker was the secondary importance, from the pilot's point of view, of the currently popular controversies over the best configuration—straight, swept, or delta plan form, high or low horizontal tail, etc. The pilot's primary concern is how the airplane flies. Was it designed with adequate basic stability to make it a good gun platform? Does it have good control in the transonic region? In the area of specific recommendations, Mr. Le Vier mentioned several so-called "gadgets" that he considered worth while. Among these are rate dampers and incremental control. He also indicated a desire for better ways to get out of the airplane when needed. Speaking on operations, he advocated the straight-in landing approach and pointed out the advantage, during a dead-engine descent, of coming down in a glide configuration rather than a landing configuration. In this way, greater speed—and hence greater control—is realized with only a slight increase in sinking speed. He also evidenced concern over the increasing danger of fighter aircraft being unable to return to base because of lack of fuel as a result of a few extra minutes spent in combat. This situation is caused by the high rate of fuel consumption during afterburner operation.

In conclusion, Mr. Le Vier urged that test pilots work more closely with every group involved in design and suggested that engineers might ask themselves, "Would I want my son to fly the airplane I am designing?"

After the formal presentation, Rudolph L. Thoren, Chief Flight Test Engineer at Lockheed, who had introduced the speaker, conducted a lively question period. Section Chairman Warren Dickinson then adjourned the meeting with the hope that the Section would invite test pilots more often to give "their side of the picture."

Ray Reimer
Member, Specialist Meetings Committee

Ralph E. Van Deventer, Vice-President—Materials and Process, Alloy Engineering and Casting Company, Champaign, Ill., addressed a group of 65 members and guests of the Los Angeles Section at a specialist meeting held on February 8. The talk was entitled "Design Benefits from Application of Process Controls."

The speaker brought out the fact that castings could be advantageously used in place of forgings in many aircraft applications, if advanced process controls—including mechanical and metallurgical tests—were applied in the design stage. He stated that small quantities and rapid obsolescence have limited the development of castings in favor of forgings. However, the flow lines in forgings can be the cause for limitations to their use, while the properties of castings can be controlled by proper attention to process controls. The presentation was concluded with slides illustrating the development of cast parts at Studebaker-Packard Corporation.

St. Louis Section

L. A. Smith, *Secretary*

The January 26 meeting of the St. Louis Section was held jointly with the National Aeronautic Association (St. Louis Section) at the Engineers Club. Fifty-five members and guests attended.

Vice-Chairman F. L. Doblhoff welcomed members and guests to the meeting and announced that the Chairman was attending the IAS Annual Meeting in New York.

The Educational Committee reported on the Student Paper Competition, and other committees presented plans for the coming months.

Lou Raisch introduced the speaker of the evening, Capt. E. G. Sperry, who received the Cheney Award for development of the downward ejection seat.

Captain Sperry outlined the physiological aspects of ejection from high-speed aircraft and defined the limiting factors of escape. At present, he said, 20*g* and 390 knots I.A.S. are the limiting factors in escape without serious injury resulting. It appears that downward ejection, which was developed as an alternate escape system, has many advantages in high-speed aircraft. However, the new problem of pilot retention is created.

Research is now being conducted to define more clearly the exact parameters involved in the various modes of escape and to provide escape systems that will permit evacuation of airplanes at today's performance levels.

San Diego Section

J. M. Adamson
Corresponding Secretary

J. G. Wenzel, Section Chairman, and members of the Student Aid Committee of the San Diego Section, have been instrumental in establishing a Student Branch at San Diego State College.

Nineteen charter members have been enrolled under the Honorary Chairmanship of Charles Morgan, Assistant Professor of Engineering, SDSC.

IAS formally approved the establishment of the Branch on February 16.

Student Branches

California State Polytechnic College

Robert Evans, *Reporter*

The February 3 meeting of the California State Polytechnic College Student Branch was called to order by Secretary Gene Robinson in the absence of Chairman Jack Gresham. Forty students and faculty members were present.

After a short business meeting, Secretary Robinson introduced Harold P. Hayes, Dean of Engineering, California State Polytechnic College, who spoke on "The Engineering Outlook."

Dean Hayes began by citing some statistics pertaining to the number of engineering graduates since 1949 and the number of engineering openings in the industry for these graduates. He then went on to relate the popular feeling among most engineers and school officials about the general trends in employment. These figures and theo-

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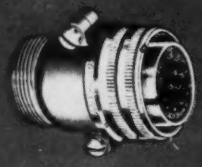

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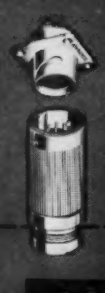

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ries were related to the estimate of expenses borne by the college and by the student himself. The type of curriculum offered and the reasons for it were discussed.

Dean Hayes then endeavored to give the sequence and explanation for the building being done on the campus at this time. The meeting was adjourned after a question session.

▶ The February 17 meeting of the IAS Student Branch was called to order by Chairman Jack Gresham. Attending were Mr. and Mrs. Wolfgang Klemperer and 80 students and faculty members.

Mr. Klemperer, a Founder and Fellow of the IAS, and a Research Engineer with Douglas Aircraft Company, Inc., in Santa Monica, Calif., spoke on "Sailplanes in the Service of Scientific Research." He commenced with an introduction to the sailplane and its general configuration and cited several records set by sailplanes. He then explained how the wind currents are utilized in ridge soaring, thermal soaring, thunderstorm and cold-front soaring, and standing wave soaring. The sailplane can be used to advantage, he said, in flight training, in sport flying and in obtaining flight-test data.

How the sailplane was used in exploring the standing wave phenomenon (Sierra Wave) in California was explained, and it was pointed out that this project required skillful flying by those who soared into the wave, braving extreme turbulence and high altitude.

The speaker showed a color movie on the Sierra Wave Project of 1949–1951. The film showed the cloud formations in the wave, cloud characteristics, ground observation methods, recording devices, and the sailplanes. Another motion picture showed the sailplane activity and equipment. The film program closed with a movie of early sailplane activity in Europe. The meeting adjourned to allow those present to look through the reports and literature brought by Mr. Klemperer.

Indiana Technical College

Bernard E. Heyl, *Secretary*

Forty-two students attended the final meeting of the winter term at Tech, with John Wright presiding. Midway through the meeting, the Chairman's gavel was turned over to the incoming Chairman, Norman L. Baker. The other new officers assumed their posts at the same time.

A field trip to be held during the spring term was discussed. It probably will be a visit to the Chicago Museum of Science and Industry. Committeemen for the various "open house" projects outlined progress to

Professor Ben L. Dow, Honorary Chairman, presented membership cards and pins to eight incoming members and announced the reinstatement of one former Branch member.

The meeting closed after the showing of two films, *Attitude Gyro* and *Harnessed Lightning*.

Iowa State College

John L. Midgorden, *Secretary*

The January 12 meeting of the IAS Student Branch was called to order by Chairman Philip Smith. The regular business session was omitted in order to allot more time to the guest speaker.

John Yardley, a Stress Project Engineer for McDonnell Aircraft Corporation, spoke on "Industry and the Young Engineer." Mr. Yardley was graduated from Iowa State in 1944 with a degree in Aeronautical Engineering.

The object of his talk was to give a picture of a typical aircraft plant and what a young engineer could expect upon entering the aircraft industry. He outlined the organization of a typical aircraft plant with the following main divisions—engineering, manufacturing, sales and service, personnel, and management—and discussed each division briefly, with most emphasis on the engineering section.

Then, in order to give the members an idea of what problems are encountered in building modern aircraft, Mr. Yardley followed through a hypothetical design problem from the time it was simply an idea in the designer's mind until the final product rolled off the assembly line. His talk was illustrated with slides of some of McDonnell's facilities and products.

▶ The February 9 meeting of the IAS Student Branch was held in Marston Hall, following the retaking of the yearbook photo in the Student Memorial Union. Chairman Philip Smith called the meeting to order.

Glen Christoffersen and James Iverson were named Co-Chairmen for the Aeronautical Engineering Veishea Open House. "Veishea" is the student-run festival held each spring.

Glen Murphy announced that Capt. James Laurence Pritchard, former Secretary of the Royal Aeronautical Society, Great Britain, would speak on "Gas Balloons and Gas Turbines" on February 25. Captain Pritchard, a graduate of Cambridge University, wrote several mystery novels years ago. After becoming interested in aeronautics, he wrote an early British book on aircraft structures. He served in the Royal Navy during World War I. An Honorary Fellow of both the IAS and RAeS, Captain Pritchard has been making a lecture tour in the United States.

The evening's program consisted of reports by two students. James Bone spoke on "Inerting Aircraft Fuel Tanks," presenting the system proposed by Howard W. Naulty, of Cornell Aeronautical Laboratory, Inc. The speaker said that Mr. Naulty found in his studies that inerting fuel tanks was inexpensive and practical weightwise. For example, the unit he proposed would weigh only 35 lbs. for a DC-7 transport; if the system saved only one airplane over a period of several years, this saving alone would pay for the weight increase penalty for 50 years.

The advantages of such a system include protection from electrical discharges in the atmosphere or in the aircraft's electrical system itself and protection from dangers of ground maintenance, such as sparks and refueling hazards.

The supply of inert gas in Mr. Naulty's system, Bone said, would come from the exhaust system of the airplane's power plant. This gas would be run through a heat exchanger and purifier before being allowed to enter the fuel tanks. Because of the presence of this inert gas in the gas tanks, the highly combustible mixture of air and fuel vapor no longer exists in dangerous quantities.

The second report was given by Robert Mullenger on "Comparison of Axial and Centrifugal Compressors." He pointed out advantages of the axial-flow compressor, such as smaller diameter with less frontal area and consequently less drag and higher compression ratio for more efficiency. On the other hand, the centrifugal compressor is a lighter unit per pound of thrust, is less vulnerable to objects entering through the diffuser, and has a larger critical operating range. As far as maintenance is concerned, the centrifugal is better because of its simplicity.

Although most of these advantages seem to be in favor of the centrifugal compressor, Mullenger said, the most desirable characteristics of efficiency and frontal area rest with the axial-flow compressor. The latter, therefore, is being used almost exclusively in jet engines.

Kent State University

Richard A. Hole, *Secretary*

The Kent State University Student Branch of the IAS was organized on February 9. The following officers were elected: Michael Ramicone, Chairman; Carl W. Goodin, Vice-Chairman; Richard A. Hole, Secretary-Treasurer; and Donald Straley, Staff Assistant. Peder A. Otterson, Instructor in the Department of Aviation Technology, is the Honorary Chairman.

Students in the Department of Aviation Technology have shown a great deal of enthusiasm for our recent affiliation with the IAS. It is our goal to become one of the most active Student Branches of the IAS.

▶ On February 24, members of this Branch attended a joint dinner meeting of the IAS Cleveland-Akron Section and the American Rocket Society. The guest speaker was Walter R. Dornberger, Guided Missile Consultant, Bell Aircraft Corporation, whose speech is discussed on page 134 of this issue.

Pennsylvania State University

E. Allen Weber
Secretary-Treasurer

Forty members attended the IAS Student Branch meeting at Penn State on February 17, with Ralph Straley presiding.

John Fox, Faculty Adviser, again urged the seniors to get their papers written in time for the contest.

A motion picture obtained from the Navy Department and entitled *NADC —Johnsville, Pa.* was shown. It described in colorful detail numerous research projects in progress at the Naval Air Development Center in Johnsville, Pa. Just a few of the topics covered in the film were: a human centrifuge developing a force of several g's; man's behavior at high altitudes; drone aircraft experiments using B-17's; launching of rockets and guided missiles; constructing photographic equipment for fast planes; and developing better devices such as automatic pilots and navigation aids.

Purdue University

John F. Andrews, *Secretary*

George J. Clingman, Powerama Supervisor, Allison Division, General Motors Corporation, spoke on "Turboprops" at the February 8 meeting at Purdue, which was attended by 43 Student Members and guests. He discussed some of the problems and advantages and the possible future of this type of power plant in commercial aviation.

The following new officers were elected: Roy Austin, Chairman; Ronald Lang, Vice-Chairman; John Andrews, Secretary; and Frank Britt, Treasurer.

Professor E. F. Bruhn and Prof. L. T. Cargnino will serve as Faculty Advisers. Ernest Hartman was appointed Chairman of the Program Committee, assisted by Bill Fait, Lionel Wilson, Dean Hofferth, and Samuel Hutchinson. Bob Landes and John Toney were named to the Publicity Committee.

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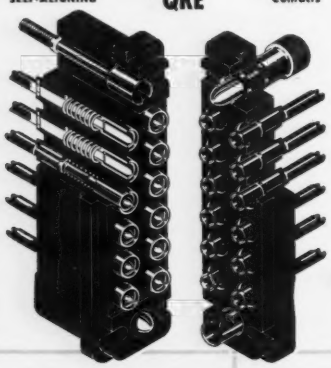

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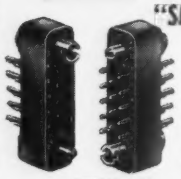


7, 14, 20, 26, 29, 34 Contacts

ACTUAL SIZE

HEAVY DUTY **TYPES "200" to "900"**

Used in "AN" Shells

¼ ACTUAL SIZE

SERIES "M" MINIATURE

4, 5, 7, 9 Contacts

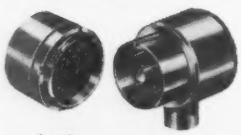
ACTUAL SIZE

SERIES "HM" HERMETIC PLUG (Round Hole)

Used with "M" Receptacles

ACTUAL SIZE

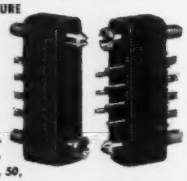
TYPES "RA" & "RB" WATERPROOF



4 or 9 Contacts

½ ACTUAL SIZE

SERIES "MRE" MINIATURE



7, 8, 9, 14, 18, 20, 21, 26, 34, 41, 50, 75 Contacts

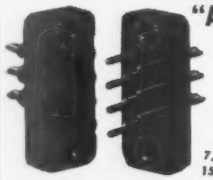
½ ACTUAL SIZE

SERIES "HMRE" HERMETIC PLUG

Used with "MRE" Receptacles

ACTUAL SIZE

AIRCRAFT **SERIES "A"**



7, 10, 15, 18 Contacts

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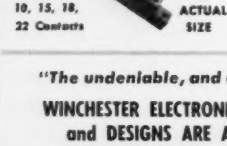
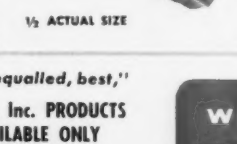
SERIES "K" RECEPTACLES Used with Printed Circuit Cards



2, 3, 6, 10, 15, 18, 22 Contacts

⅓ ACTUAL SIZE

TYPE "B" MOISTURE PROOF



12, 14, 24 Contacts

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Rensselaer Polytechnic Institute

Richard C. Kennedy
Secretary

The R.P.I. Student Branch held its monthly meeting on February 16 in the School's Aeronautics Department. Chairman Robert Whitten presided over the meeting, at which 60 members were present.

The evening's feature was a talk on new seaplane developments by John Decker. Mr. Decker, a 1944 graduate of this school, is now associated with the aerodynamics division of The Glenn L. Martin Company.

With the advent of jet propulsion, as Mr. Decker explained, came new hope in the field of high-speed seaplane design. One of the greatest obstacles that faced the designer in using conventional propellers was that of keeping the tips of the blades out of green, or solid, water. The jet engine eliminated this problem so that the contours of the fuselage could be lowered closer to the water. The result of this is less frontal area. Other factors which lead to an optimistic view for the seaplane are the use of the long-hull afterbodies and the elimination of the long-runway problem.

Mr. Decker then compared the design and performance problems and characteristics of the land plane and the seaplane, showing that a flying boat may actually be built lighter than a land plane to perform a specific mission. It was also pointed out that the seaplane may be of great strategic value in the event of intercontinental warfare.

To complete the evening, motion pictures were shown of the P5M-2 Marlin in rough-water tests off Norfolk in addition to the first roll-out pictures of the XP6M-1 Seamaster, Martin's new jet flying boat.

San Diego State College

Formal approval of the establishment of a Student Branch at San Diego State College was given by the IAS on February 16. Charles Morgan, Assistant Professor of Engineering, SDSC, will serve as Branch Faculty Adviser and Honorary Chairman.

The Charter Members are Wallace Anderson, William Boram, Richard Bouley, Sim Frahm, Roger Giacolett, R. W. Gowdy, James Harrison, Thomas R. Hemphell, R. W. Johnson, Terry N. Lauritsen, Jim McNeil, Willard Merrill, James Monroe, Robert A. Parker, Robert R. Perry, Lewis E. Ross, William H. Vassis, Donald R. Whisler, and Ronald Whisler.

Tri-State College

George Esenwein, Jr., *Chairman*

The fall session opened with Robert Spatz serving as Chairman of the Tri-State IAS Student Branch. Through his efforts on registration day, 58 aeronautical students were signed up in the IAS. After the first coffee-and-doughnut session to get acquainted with the new students, the Branch seemed to take on a new spirit. For the rest of the term, 75 to 80 per cent of the members turned out for meetings.

A banquet in honor of December graduates was held at Twin Gables, Columbia, Ohio. The guest speaker was Obed Wells, a Project Engineer for Cessna Aircraft Company, who outlined some of the problems and methods encountered in the structural testing of airplanes in industry. Using slide films, Mr. Wells showed actual test setups and results as the structure being tested underwent various loadings. For the students, this talk demonstrated actual application of some of the principles that are studied in college.

The Scholastic Award was received by Gerald Lutz for having the highest point average of the graduating IAS members. The IAS Lecture Award went to George Esenwein, Jr., for his presentation of "Some Aspects of Inlet Design for Supersonic Aircraft."

For the winter term, the Tri-State Branch was headed by George Esenwein, Jr. During the 2 days of registration, 60 students were signed for membership. At the first meeting, the Chairman outlined the functions and national organization of the IAS.

Regular meetings this term and last term were supplemented with films, most of them obtained through the IAS. One motion picture of particular interest was shown by Robert R. Spatz, our ex-F9F-6 pilot. He made it himself aboard the carrier U.S.S. "Wasp" while on a shakedown cruise. Bob's film showed the topside activities aboard the carrier during the take-off and landing phase of the air operation. The consensus of the members, after seeing Bob's film and hearing his enthusiastic explanation of events, was, "Navy, here we come!"

An outgrowth of the business meetings this term was the adoption of a rule that more comprehensive records be kept of the Branch's activities. Previously, the only records were those maintained by each officer and kept in his own folder. Since these folders changed ownership each term, much data that should be on permanent file has been misplaced. The new system requires that at the end of each term the accumulated records of the various officers be filed permanently in the Aeronautical Department office.

As this term is the time for organizing the field trip and senior banquet, two committees were selected. The Banquet Committee set up tentative plans so that a speaker could be engaged early. The Field Trip Committee sent letters requesting permission to visit several different aircraft companies in the Midwest. To be more specific, three tentative trips were adopted: Cleveland–Columbus, Columbus–Dayton, and Indianapolis–St. Louis. Since the correspondence is not complete at this date, the final decision on what trip is to be taken probably will be made at the first meeting next term.

Lawrence D. Crowley has been elected to head the Tri-State Branch next term.

The Branch extends the "best of luck" to its Honorary Chairman, Prof. Quintin J. Hawthorne, on his forthcoming excursion to Alaska. The 3-week trip will start the first week in March.

U.S. Naval Postgraduate School

Richard J. Peterson
Corresponding Secretary

The Student Branch met on February 9 to hear D. H. Seager, Research Aerodynamicist, Lockheed Aircraft Corporation, speak on recent fighter aircraft developments.

Mr. Seager first outlined the advantages and disadvantages of various high-speed aircraft configurations from the aerodynamic standpoint, concluding that the thin low aspect ratio wing seems to offer the best solution to most problems. He then discussed the design features of the Lockheed VTO and the F-104.

▶ On February 23, the Student Branch heard H. H. Denlinger, Staff Engineer, Convair, San Diego, Division, in a similar presentation. He discussed the Convair "Navy Family"—the F2Y-1 Sea Dart, XFY-1 VTO fighter and R3Y-1 Tradewind—with a review of their development and projected uses.

University of Detroit

Eugene Rooney, *Secretary*

John Squires, of Continental Motors Corporation, spoke on "The Small Gas Turbine" at the December meeting of the IAS Student Branch. Using slides, he explained the operation and specifications of gas turbines of various sizes and enumerated the uses to which they are now being put.

Speculating on other possible uses of gas turbines, Mr. Squires suggested that they might be used as power plants in training aircraft in which pilots would make the transition from propeller-driven to jet-powered airplanes and as power plants for helicopters, since they offer easy mounting and great reduction in vibration.

At a business meeting following Mr. Squires' presentation, the following officers were elected: Allen Strickfaden, Chairman; Donald Palermo, Vice-Chairman; John Nassr, Treasurer; and Eugene Rooney, Secretary.

University of Illinois

James Baker, *Secretary*

The University of Illinois Student Branch of IAS held its first meeting of the spring semester Wednesday, February 23, in the Electrical Engineering Building. Fifty-seven members and prospective members were present. Chairman Jim Kuczma presided at the meeting and explained briefly the functions of the organization.

A short business meeting was held. The minutes of the previous meeting were read, and a Treasurer's report was given. A brief report concerning Engineering Open House was given by Engineering Council Representative John Kistenbroker.

Dr. H. H. Hilton introduced the guest speaker, L. M. Weeks, Chief of Preliminary Design, McDonnell Aircraft Corporation. Mr. Weeks gave an interesting talk on aircraft structural problems due to elevated temperatures. The talk, which covered typical problems, was illustrated with slides and photographs.

One item Mr. Weeks discussed was how a careful investigation of the temperature variation through a canopy enabled the designers to continue using plexiglas. Calculations using an average temperature had previously indicated that glass would be necessary. The use of plexiglas has meant a weight saving of 250 lbs.

▶ The University of Illinois Student Branch of IAS held its second meeting of the spring semester on March 2 in the Electrical Engineering Building. Fifty-one members were present. Chairman Jim Kuczma called the meeting to order.

A short business meeting was held. The minutes of the previous meeting were read, and a Treasurer's report was given. Engineering Council Representative Jim Piechocki briefly discussed the Aero Department's displays and called for an all-day effort Saturday, March 5, to get them set up.

Dr. H. H. Hilton introduced the guest speaker, D. R. Pearl, of Hamilton Standard Division, United Aircraft Corporation. Mr. Pearl, a former student at the University of Illinois, spoke on "Engineering Successful Aircraft Machinery." The talk covered some of the special requirements and specifications that aircraft machinery must meet, an

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Aluminum components of the Schweizer 1-23 sailplane, shown in flight, are protectively finished with "Alodine" No. 1200.

Alodizing provides a durable bond for paint, and greatly enhances aluminum's corrosion resistance. This ACP process meet the requirements of Military Specification MIL-C-5541.

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outline of the designing of a hydraulic relief valve, and the desirable qualities of an engineer.

Some of the special requirements that aircraft machinery must meet were typified by those for a fuel-control system. These included extreme temperature variations, wide range of weight flow of fuel, accuracy of metering, and large pressure variation, as well as the inevitable requirements of compactness and light weight.

The design of a relief valve was given as an example of the many problems that may arise even from such a prosaic item. Mr. Pearl showed how conditions arising from large pressure variations, vibrations, and accelerations might be overcome.

He then outlined the qualifications an engineer should have. These were a solid technical background, good judgment, integrity, and perseverance. With regard to the last item, Mr. Pearl passed along an idea given to his graduating class in 1941 by Professor Leutwiler. Professor Leutwiler believed that a sound policy for achieving success was to give $1.10 worth of effort for every dollar one is paid.

University of Maryland

George Maggos, *Recording Secretary*

On the night of February 9, the IAS Student Branch of the University of Maryland held its meeting at the Naval Ordnance Laboratory at White Oak, Md. Professor A. L. Guess, University of Maryland, and Hermann H. Kurzweg, Head, Ballistics Laboratory, NOL, arranged for an inspection and demonstration tour of the laboratory's supersonic and hypersonic wind tunnels, ballistics ranges, and shock-tube wind tunnel.

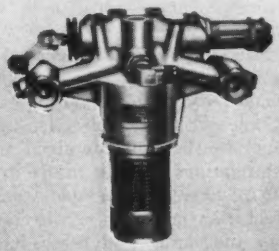
The laboratory's function is to produce new weapons for the Navy. This is accomplished through laborious research and testing. Some of the facilities that are available for testing new missile configurations are the intermittent and continuous wind tunnels.

To simulate the manner in which projectiles revolve as they travel at supersonic speeds, the sting that supports the model is equipped with an enclosed turbine. The turbine is run by a controlled amount of compressed air. The compressed air flow is inside the sting and causes the model to rotate.

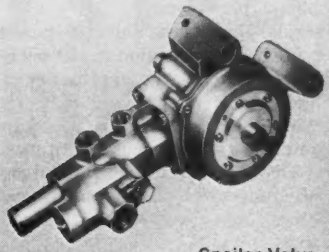
The hypersonic wind tunnel is capable of reaching Mach 10 by preheating the air before it passes through the De-Laval nozzle.

Also viewed by the students was the shock-tube wind tunnel. Although its running time is only in the microseconds range, over 200 Schlieren pictures can be taken by the NACA-developed ultra-high-speed camera. This camera is

Strut Assembly—
Main Landing Gear Retract



Valve Assembly—Steering Metering



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High Heat Treat
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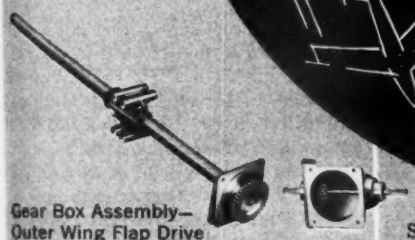
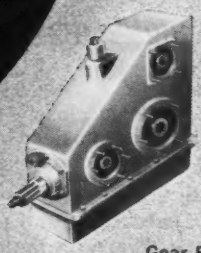
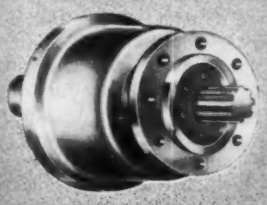


Gear Box Assembly—
Outer Wing Flap Drive



Gear Box



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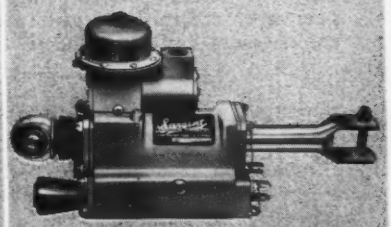

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The final phase of the tour consisted of observing a demonstration in the open-air ballistics range, over 300 ft. long.

There is also an enclosed ballistics range, capable of simulating pressures encountered at various altitudes. Thirty-eight cameras are lined up along the two ranges for photographing the projectiles at various stations along the range.

University of Oklahoma

Carroll E. Gregg, *Secretary*

Chairman Roy A. Campbell presided at the February 22 meeting of the University of Oklahoma Student Branch. Fifty-nine members and guests were present.

Herman O. Ankenbruck, Senior Aerophysics Engineer of Convair, a division of General Dynamics Corporation, spoke on "Some Problems of High-Speed Airplanes." His talk contained these points: relations between groups in the aircraft industry; high temperatures as a structural problem; directional stability and control; dynamic lateral stability; and specific problems of high-speed airplanes and their solutions.

Jack E. Hicks, Project Design Engineer in Convair's Power Plant Design Group, attended the meeting with Mr. Ankenbruck.

Allen Dayton and Robert Patchett were appointed Co-Chairmen of the Activities Committee. Jim Maupin was named Chairman of the Refreshment and Entertainment Committee; Jerry Mrazek and William Harrington volunteered to serve on this committee.

▶ Chairman Campbell presided at the March 8 meeting of our Branch. Twenty-six members and guests were present.

Since this meeting was held for the presentation and judging of four student papers, Prof. L. A. Comp, Faculty Adviser, started the meeting off by introducing the three faculty judges who were to select the two winning papers that would represent our Branch at Fort Worth in April. The judges were Prof. Ellis M. Sims, Prof. Fred R. Mouck, and Associate Prof. William L. Corey.

The papers and those presenting them are: "Strain Gage Dynamometer" by Kenneth Barnes; "Matrix Solutions of Problems of Structures" by Donald Boulton; "Effect of Design and Position of Tail on Longitudinal Control in the Transonic Speed Range" by Jerry Mrazek; and "Construction and Analysis of a Subsonic Air Supply for Aeronautical Research" by Carroll Gregg. Messrs. Barnes and Gregg were chosen by the judges to represent our Branch at the Third Southwestern Student Competition.

University of Tulsa

Lloyd T. Richardson
Secretary-Treasurer

The final meeting of the Tulsa Student Branch of the IAS for 1954 was held on December 16. The meeting was attended by eleven members and was presided over by Don Boyd, Student Chairman. The speaker was E. W. Garrison, Design Engineer, Air Conditioning Group, Douglas Aircraft Company, Tulsa. Mr. Garrison spoke on the cooling problem in modern airplanes, in particular the RB-66, for which he helped design the electronic cooling system. Before the meeting closed, two films were shown, *Exercise Test Drop*, about the C-124 Globemaster, and *New Wings for the Navy*, a film on the tests of the A4D Skyray.

Two of our members placed in the ASME competitive paper contest. Don Funk took first place, winning $39 worth of books. Gerald Stevens won a smaller prize.

▶ On January 20–21, seven members of the Tulsa Student Branch made a field trip to Wichita, Kan., to tour the plants of Boeing Airplane Company and Beech Aircraft Corporation. Our hosts were Jack Duckworth and Jim Moore at the Boeing plant and Roy Kunz at the Beech plant.

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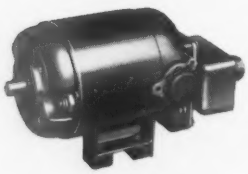

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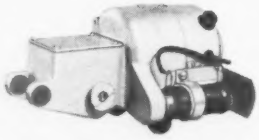
This can mean improved product appearance, reduced weight, greater compactness and lower costs.



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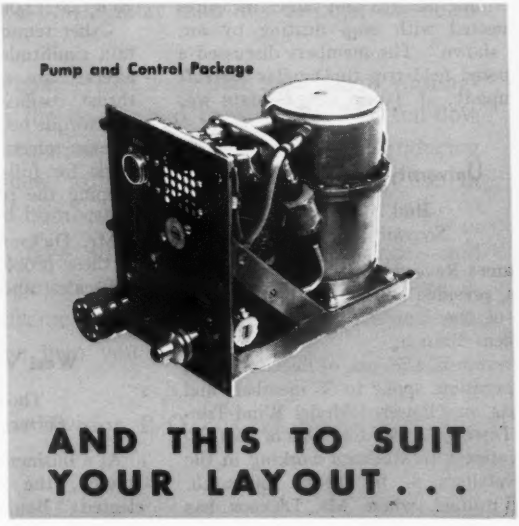

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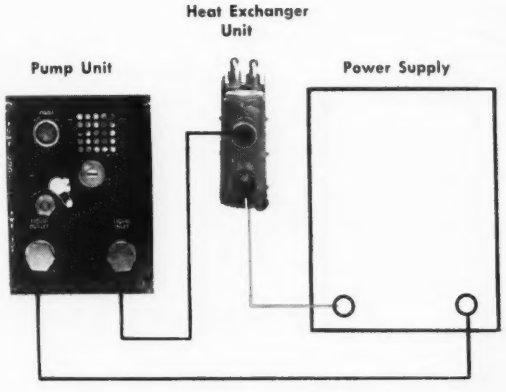

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▶ The February 18 meeting of the Tulsa Student Branch was attended by 16 members, with Don Boyd in the chair. Lloyd T. Richardson was elected Secretary-Treasurer. After being elected, he made a talk on "How to Get Your Job," based on the SAE pamphlet of that title.

A film entitled *Wings of Agriculture*, describing hazards and safety measures connected with crop dusting by air, was shown. The members discussed a proposed field trip to Douglas Aircraft Company, at Tulsa, but no date was set.

University of Washington

Bud N. Nelson
Secretary-Treasurer

James Reverdy Allender, Vice-Chairman, presided at the January 21 meeting of the University of Washington Student Branch.

Preston E. Dickson, of Beech Aircraft Corporation, spoke to 55 members and guests on "Powered-Model Wind-Tunnel Testing." The talk was of particular interest to students working in the University's 8- by 12-ft. 250 m.p.h. wind tunnel, where Mr. Dickson has been conducting power tests for the past year.

Mr. Dickson, who is Group Engineer for Experimental Aerodynamics and Flight Test at Beech Aircraft, described the requirements for powered-model testing.

The speaker pointed out that power testing for multiengined executive type aircraft has become important in the postwar years. There has been a trend toward increased horsepower in standard production airplanes, with low air speed and high asymmetric power creating a real directional control problem.

The actual testing can be done by either of two types of power settings, constant power or constant thrust coefficient, depending upon the particular wind tunnel. A small-diameter motor, to fit today's small nacelles, is required for the reproduction of scale power. Mr. Dickson said that recent tests with a 1/6-scale model employed four pole a.c. motors measuring $2^1/_2$ in. in diameter and 8 in. long and producing 20 hp. at 12,000 r.p.m.

Other requirements necessary to obtain similitude of model and full-scale aircraft are reproduction of full-scale thrust coefficient, propeller efficiency, and torque coefficient. Also important are the selection of the propeller-blade angle for full-scale advance ratio and keeping the propeller configuration to scale.

Mr. Dickson described his solutions to these problems, using cross plots of full-scale and model characteristic curves.

West Virginia University

Thomas G. Gainer
Corresponding Secretary

At a business meeting of this Student Branch, the following officers were elected: Benjamin D. Grove, Chairman; James Heavner, Vice-Chairman; D. Richard Walters, Secretary-Treasurer; Thomas G. Gainer, Corresponding Secretary; Ronald Curry, Program Chairman. Professor Leon Z. Seltzer will continue as Faculty Adviser and Honorary Chairman of the Branch.

Professor Seltzer discussed plans for the Southeastern Regional Conference to be held at Virginia Polytechnic Institute on April 7, 8, and 9. Professor Seltzer is to be the featured speaker at the April 8 session.

Samples of prize-winning papers from last year's regional competition were displayed at this meeting of the Branch.

At the conclusion of business, the film, *The F-86E Sabre Jet*, was shown.

Members Elected

The following applicants for membership or applicants for change of previous grades have been admitted since the publication of the list in the last issue of the REVIEW.

Transferred to Associate Fellow Grade

Arnold, J. Elwood, M.S. in M.E., Mgr., Convair, Daingerfield, a Div. of General Dynamics Corp.

Baird, Eugene F., M.S.M.E., Chief Flutter & Vibrations Engr., Grumman Aircraft Engineering Corp.

Burgess, Neil, M.S.E.E., Mgr.—J 79 Proj., Jet Engine Dept., AGT Div., General Electric Co. (Cincinnati).

Glass, Irvine I., Ph.D., Asst. Prof. of Aero. Engrg. & Research Assoc. in Aerophysics, Inst. of Aerophysics & Dept. of Aero. Engrg., Univ. of Toronto.

Lawrence, William C., B.S. in Ae.E., Asst. V-P—Engrg., Overhaul & Supply Depot, American Airlines, Inc. (Tulsa).

Sweet, Floyd J., B.S. in Ae.E., Lt. Col., USAF; Asst. Executive Secretary, Scientific Advisory Board, Office, Chief of Staff, Hq. USAF.

Towner, George F., B.S. in M.E., Proj. Mgr., Bomber Defense Systems, Air Arm Div., Westinghouse Electric Corp. (Baltimore).

Elected to MEMBER Grade

Bentley, Richard M., B.E. (Cum Laude), Aeronautical Engineer—Electronics, Guided Missiles, Hughes Aircraft Company.

Bevan, Fred T., Design Engr. "A," Lockheed Aircraft Corp. (Burbank).

Brown, James D., B.S., Field Installation Engr., United Aircraft Service Corp.

Eggert, Arthur E., M.S., Service Engr., Minneapolis-Honeywell Regulator Co.

Frailey, Jack H., A.E., Proj. Dir.—Research, Flight Control Lab., M.I.T.

Graziano, William D., M.S. (Aero.), Struct. Engr., North American Aviation, Inc. (Los Angeles).

Hall, William H., M.E., Dir.—Design Engrg., Maintenance & Engrg. Dept., American Airlines, Inc.

Jarmie, Louis, Supvr.—Engrg. Publications, Frank Mayer Engineering Co.

Johnston, J. Ford, B.S. in M.E., Group Engr.—Flight Dynamics, Lockheed Aircraft Corp. (Burbank).

Lange, Donald E., B.S. in M.E., Test Pilot, Flight Research Dept., Sperry Gyroscope Co.

Laufer, Max M., Chief Surveyor, Airworthiness Authority, Ministry of Transport & Comm. Dept. of Civil Aviation, Govt. of Israel.

LeVine, Joe W., B. of Ae.E., Sr. Structures Engr., Convair, San Diego, a Div. of General Dynamics Corp.

Lucas, Robert W., Operations Chief, NAI Wind Tunnel, Northrop Aircraft, Inc.

Mapp, Robert, B.S., Asst. Chief, Engrg. Dept., Evaluation Branch, Directorate of Flight & All-Weather Testing, U.S. Govt., Dept. of Defense, WCTEE, Wright-Patterson AFB.

Nisley, John D., Supvr., Power Plant Sect., Engrg. Dept., Aircraft Div., Hughes Tool Co.

North, Gilbert B., B.S. in Ae.E., Test Pilot, McDonnell Aircraft Corp.

Paintin, Thomas E., B.S.E.E., Lab. Analyst "A," Douglas Aircraft Co., Inc. (Santa Monica).

Reissig, Robert R., Administrative Engr., Guided Missiles Div., Republic Aviation Corp.

Rosengren, S. N., B. of Ae.E., Design Coordinator, Fairchild Aircraft Div., Fairchild Engine & Airplane Corp.

Spearman, William E., B.S. in Tech., Asst. to Asst. V-P, Overhaul & Supply Depot, American Airlines, Inc. (Tulsa).

Travers, William R., Mgr.—Devel. Dept., Marketing, General Electric Co. (Cincinnati).

Volk, Joseph A., Ph.D. (Geophysics), Elect. Engr., Dir.—Research, The Greenleaf Mfg. Co.

Wallis, John W., B.S.Ae.E., Staff Asst., Military Relations Dept., Northrop Aircraft, Inc.

Young, Charles E., M.S., Assoc. Research Physicist, Cornell Aeronautical Lab., Inc.

Transferred to MEMBER Grade

Baylor, Robert N., B.S. in Ae.E., Stress Analyst "A," Temco Aircraft Corp.

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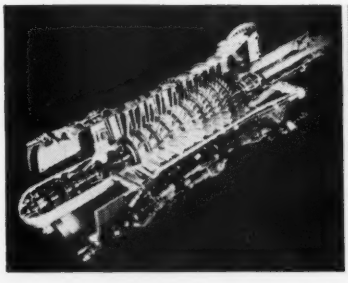

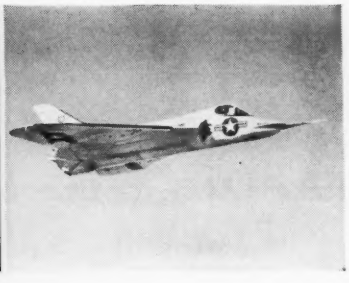

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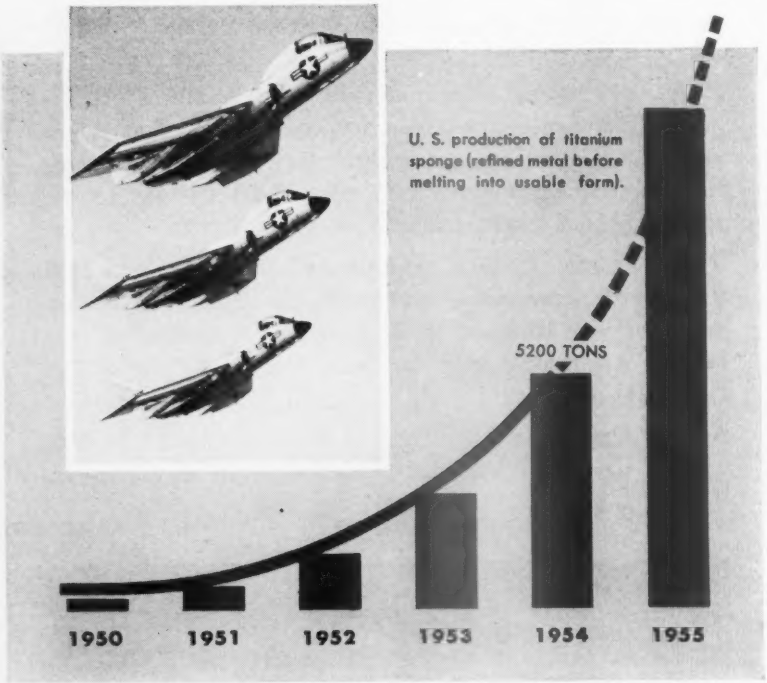

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Brown, Wilbur W., B.S. in Ae.E., Sr. Struct. Engr., Convair, Ft. Worth, a Div. of General Dynamics Corp.

Campbell, Francis W., B.S.E.E., Lt. Col., USAF; Asst. Guided Missiles Chief, Fire Control Branch, Armament Div., AFMME, DCS/M, Hq. USAF (Pentagon).

Hillel, Arie, B.Sc., Head, Proj. Sect., Engrg. Dept., Israel Defence Forces Air Force.

Kuchar, Charles E., M.S. in Ae.E., B-58 Performance Group Lead Engr., Convair, Ft. Worth, a Div. of General Dynamics Corp.

Lowe, Harold W., B.S. in Ae.E., Aerodynamics Engr., Temco Aircraft Corp.

Mabry, Irvin C., B.S. in Ae.E., Asst. Proj. Engr., Reaction Motors, Inc.

Mauersberg, Jack D., B.S.M., Research Assoc., The Ohio State Univ. Research Foundation.

Murphree, William D., M.S. in Engrg., Aero. Research Engr., Flight & Aerodynamics Lab., Research Div., Ordnance Missile Labs., Redstone Arsenal.

Schoenberg, Charles M., M.S.E. (Aero.), Aerodynamicist, Douglas Aircraft Co., Inc. (Santa Monica).

Schrier, Jack, B. of Ae.E., Mgr., Special Products Sale, Avien, Inc.

Seide, Paul, Ph.D. (Engr. Mech.), Technical Staff, Ramo-Wooldridge Corp.

Shutte, Robert H., M.S. in Ae.E., Aerodynamicist, Douglas Aircraft Co., Inc. (Santa Monica).

Stinson, William H., B.S. in Ae.E., Engrg. Test Pilot, Cessna Aircraft Co.

Elected to Associate Member Grade

Ashworth, J. Edward, Dayton Rep., Lycoming Division, AVCO Mfg. Corp.

Denning, Vaughn E., B.S.M.E., Capt., USAF; Research & Development Staff Officer, Hq. USAF (Washington, D.C.).

Elected to Technical Member Grade

Barclay, John H., B. of Ind. Training, Asst. Administrative Engr., Chicago Aerial Industry, Inc.

Kuntzel, K. O., CE (MED), Design Engr., SAAB Aircraft Co. (Sweden).

Preble, Robert E., Departmental Asst., Ryan Aeronautical Co.

Smith, Frank T., M.S., Aerodynamicist, Missile Systems Div., Lockheed Aircraft Corp. (Van Nuys).

Stephens, Robert W., B.S. Aero., Flight Test Supvr. (XT-37), Cessna Aircraft Co.

Stuart, Jack M., B.S.M.E., Jr. Design Engr., Chance Vought Aircraft, Inc. (Dallas).

Tapper, Charles E., Jr., B.Sc.M.E., Assoc. Research Engr., Boeing Airplane Co. (Seattle).

Veltre, Gerald J., Engrg. Designer, Airborne Accessories Corp.

Wood, Edward R., B.C.E., Instructor, Civil Engrg. Dept., Yale Univ.

Zimay, Donald R., Jr. Engr., Aero Physics Div., Cook Research Labs.

Transferred to Technical Member Grade

Abarbanel, Saul S., Graduate Student (Research Asst.), M.I.T.

Ariano, Don, Sr. Draftsman, Cook Research Labs.

Birdwell, Carl, Jr., B.S. in Ae.E., Lt., USN; Naval Aviator; Graduate Student, M.I.T.

Birrer, Lloyd G., Jr., B.S., Engr.—Designer "A," Interstate Engineering Co.

Blalock, Dana L., B.S. in Ae.E., Pvt., USA; Asst. Proj. Engr., 9203 TU TC TRAD Com. (Ft. Eustice).

Bodner, Robert E., B.S., Lt., USAF; Student Pilot, Class 56-I (Stallings AFB).

Boenig, Fred H., B.S.M. (Aero.), 2nd Lt., USAF; Aircraft Maintenance Officer (Goodfellow AFB).

Bower, John W., Engr., Propulsion Center, North American Aviation, Inc. (Los Angeles).

Bowyer, James M., Jr., M.S.

Brown, Robert M., B.S. in Ae.E., Lt., USAF.

Bryan, L. Glyn, B.A., 2nd Lt. & Flight Trainee, USAF.

Ciccone, Joseph John, Design Engr., Grumman Aircraft Engineering Corp.

Coffman, Harold V., B.S. in Ae.E., Assoc. Engr., The Glenn L. Martin Co.

Dees, Marion J., B. of Ae.E., Assoc. A/C Engineer, Stress Group, Lockheed Aircraft Corp. (Marietta).

Doss, Robert F., B.S. in Ae.E., Lt., USN; Naval Aviator.

Duffin, John D., S.B. in Ae.E., Jr. Engr., North American Aviation, Inc. (Los Angeles).

Eliot, Donner C., Stress Engr., Century Engineers, Inc.

Groover, T. G., B.S., Ens., USN (Air Arm); Student Pilot, NAATC, NAS, (Corpus Christi).

Hall, Jimmie Ralph, B.Sc., 2nd Lt., USAF.

Harper, David C., Aviation Struct. Mech., NAS (Jacksonville).

Harris, Ivan E., Jr., B.S., Flight Test Analyst, Douglas Aircraft Co., Inc. (Santa Monica).

Hayden, James S., B.S., Graduate Student (Research Asst.), Aerophysics Dept., Mississippi State College.

Howes, E. David, Jr., S.B. in Ae.E.

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Aeronautical Reviews

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Bibliographies on special subjects will be compiled at the rate of $2.50 per hour. *Translations* of technical literature from foreign languages may be obtained at $15 to $20 per 1,000 words, depending on the language.

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Aerodynamics

Flight Measurements of the Velocity Distribution and Persistence of the Trailing Vortices of an Airplane. Christopher C. Kraft, Jr. *U.S., NACA TN 3377*, Mar., 1955. 32 pp.

Published Reports and Memoranda of the Aeronautical Research Council. *Gt. Brit., ARC R&M 2550*, 1954. 8 pp. 90 refs. BIS, New York. $0.65. Covers R&M 2451—2550.

Boundary Layer & Thermoaerodynamics

Elementarer Beweis für die Eindeutigkeit der Strömung in der laminaren Grenzschicht zur Potentialströmung $U = u_1 x^m$ mit m ≥ 0 bei Absaugen und Ausblasen. Rudolf Iglisch. *ZAMM*, Dec., 1954, pp. 441–454. In German. Analysis for the case of an infinitely extended wedge-shaped body with a certain flare angle in potential flow round the wedge, taking into account boundary conditions for the determination of the corresponding flow in the laminar boundary layer.

The Problem of Diffusion into a Turbulent Boundary Layer from a Plane Area Source, Bounded by Two Straight Perpendicular Edges. D. R. Davies. *Quart. J. Mech. & Appl. Math.*, Dec., 1954, pp. 468–471.

Free-Flight Measurements of Skin Friction of Turbulent Boundary Layer with High Rates of Heat Transfer at High Supersonic Speeds. Simon C. Sommer and Barbara J. Short. *IAS 23rd Annual Meeting, New York, Jan. 24–27, 1955, Preprint 518.* 13 pp. 17 refs. Members, $0.50; nonmembers, $0.85.

Free-Flight Measurements of Turbulent-Boundary-Layer Skin Friction in the Presence of Severe Aerodynamic Heating at Mach Numbers from 2.8 to 7.0. Simon C. Sommer and Barbara J. Short. *U.S., NACA TN 3391*, Mar., 1955. 47 pp. 25 refs.

Similar Solutions for the Compressible Laminar Boundary Layer with Heat Transfer and Pressure Gradient. Clarence B. Cohen and Eli Reshotko. *U.S., NACA TN 3325*, Feb., 1955. 67 pp. 25 refs.

Some Considerations on Turbulent Flow with Shear. I, II. J. M. Burgers. *Netherlands, Koninklijke Nederlandse Akademie van Wetenschappen, Proc. Ser. B*, No. 2, 1953, pp. 125–147. Reprint. Experimental study of the relative frequency of patterns of turbulence of various scales at different distances from the wall in a turbulent boundary layer.

Turbulent - Heat - Transfer Measurements at a Mach Number of 2.06. Maurice J. Brevoort and Bernard Rashis. *U.S., NACA TN 3374*, Mar., 1955. 20 pp. Theoretical and experimental investigation providing essentially flat-plate results free from wall interference for a Reynolds Number range of 1.7×10^6 to 8.8×10^7.

Control Surfaces

Lift on a Bent, Flat Plate. F. Keune. (*Bericht, Aero. Versuchsanstalt, Göttingen, Luftfahrtforschung*, Mar. 20, 1936, pp. 85–87.) *U.S., NACA TM 1340*, Feb., 1955. 15 pp. Translation. Use of a conformal mapping method for direct determination of the angle of zero lift, lift coefficient, and lift-curve slope for any flap-chord ratio, flap-deflection angle, and angle of attack.

A Method for Predicting Lift Effectiveness of Spoilers at Subsonic Speeds. Arthur L. Jones, Owen P. Lamb, and Alfred E. Cronk. *IAS 23rd Annual Meeting, New York, Jan. 24–27, 1955, Preprint 510.* 11 pp. Members, $0.35; nonmembers, $0.75.

Fluid Mechanics & Aerodynamic Theory

Fluid Dynamic Effects at Speeds from M 11 to 15. Seymour M. Bogdonoff and Andrew G. Hammitt. *IAS 23rd Annual Meeting, Los Angeles, Jan. 24–27, 1955, Preprint 525.* 19 pp. 17 refs. Members, $0.50; nonmembers, $0.85. Investigation in a helium hypersonic wind tunnel at speeds up to Mach Number 15 of the phenomena of viscous-inviscid interactional effects over the fore part of a flat plate, two wedges, and a cone, with schlieren and interferometric analyses and calculations of the pressure distributions.

Hydrodynamical Equations for the Motion of Bodies of Revolution in Non-Viscous Rotating Liquid. S. D. Nigam and P. P. Chatterji. *Quart. J. Mech. & Appl. Math.*, Dec., 1954, pp. 458–461.

On Homogeneous Non-Isotropic Turbulence Connected with a Mean Motion Having a Constant Velocity Gradient. I. J. M. Burgers and M. Mitchner. *Netherlands, Koninklijke Nederlandse Akademie van Wetenschappen, Proc. Ser. B*, No. 3, 1953, pp. 228–235. Reprint.

On the Coalescence of Wave like Solutions of a Simple Non-linear Partial Differential Equation. I, II. J. M. Burgers. *Netherlands, Koninklijke Nederlandse Akademie van Wetenschappen, Proc. Ser. B*, No. 1, 1954, pp. 45–72. Reprint. Analysis in terms of the illustrative shock-wave problem in gas dynamics.

On the Effects of Uniform Suction on the Steady Flow Due to a Rotating Disk. J. T. Stuart. *Quart. J. Mech. & Appl. Math.*, Dec., 1954, pp. 446–457.

On the Propagation of Shock Waves in Regions of Non-Uniform Density. C. W. Jones. *Proc. Royal Soc. (London), Ser. A*, Feb. 15, 1955, pp. 82–99. 12 refs. Similarity solution for plane progressive waves with constant energy headed by strong shocks in a gas.

Some Heat and Mass Transfer Experiments on Humid Air in Turbulent Flow Over a Plane Containing an Isolated Cooled Region. B. N. Furber. *IME Proc.*, No. 35, 1954, pp. 847–860. 14 refs.

The Two-Dimensional Motion of a Supersonic Gas Flow. Th. Meyer. (*Mitteil. Forscharb. Gebiet Ing.*, Berlin, No. 62, 1908, pp. 31–67.) *Gt. Brit., MOS TIB/T4390*, Nov., 1954. 39 pp. Theoretical and experimental study for cases of flow round a convex corner where expansion takes place in a wedge-shaped region and round a concave corner where a compression shock occurs, with an analysis of the transition from subsonic to supersonic velocity based on a flow with linear acceleration at the axis of symmetry.

Unsteady Oblique Interaction of a Shock Wave with a Plane Disturbance. Franklin K. Moore. (*U.S., NACA TN 2879*, 1953.) *U.S., NACA Rep. 1165*, 1954. 21 pp. Supt. of Doc., Wash. $0.25.

Axially Symmetric Shapes with Minimum Wave Drag. Max. A. Heaslet and Franklyn B. Fuller. *U.S., NACA TN 3389*, Feb., 1955. 46 pp. 20 refs. Derivation of optimum design for bodies of revolution based on a quasi-cylindrical theoretical method applying boundary conditions on the surface of a cylinder to solve variational problems which are formulated from a reciprocity relation for the axial flow in terms of the drag formula involving geometry.

Base Pressure Studies in Rarefied Supersonic Flows. L. L. Kavanau. *IAS 23rd Annual Meeting, New York, Jan. 24–27, 1955, Preprint 529.* 31 pp. 35 refs. Members, $0.65; nonmembers, $1.00. Theoretical and experimental wind-tunnel investigation using a cone-cylinder model to simulate a blunt-based body of revolution in the rarefied atmospheres of high altitudes.

Experiments on Supersonic Flow Over Flat-Nosed Circular Cylinders at Yaw. II—Pressure Measurements on a Cylinder at 10° Yaw. I. M. Hall. *Philos. Mag.* (7th Ser.), Jan., 1955, pp. 53–60. Investigation utilizing surface pressure distributions at the U. of Manchester Fluid Motion Lab.

Experiments on Supersonic Flow Past Bodies of Revolution with Annular Gaps of Rectangular Section. N. H. Johannesen. *Philos. Mag.* (7th Ser.), Jan., 1955, pp. 31–39. Schlieren studies in the U. of Manchester Fluid Motion Lab. taking into account flows in dead-air regions.

Minimum-Drag Bodies of Revolution in a Nonuniform Supersonic Flow Field. Conrad Rennemann, Jr. *U.S., NACA TN 3369*, Feb., 1955. 25 pp. Derivation on the basis of linearized theory of a general expression for the cross-sectional area distribution of an optimum body of given volume and length.

A Study of the Flow About Simple Bodies at Mach Numbers from 11 to 15. A. G. Hammitt and S. M. Bogdonoff. *USAF WADC TR-54-257*, Oct., 1954. 56 pp. 28 refs. Theoretical and experimental investigation in the Princeton Helium Wind Tunnel of the viscous-inviscid interaction phenomena using a flat plate, 5° and 10° wedges, and a 10° cone model, taking into account the strong shocks near the leading edge.

Two-Dimensional Flow of a Compressible Fluid Past Given Curved Obstacles with Infinite Wakes. L. C. Woods. *Proc. Royal Soc. (London), Ser. A*, Jan. 20, 1955, pp. 367–386. 11 refs. Extension of the Helmholtz theory of incompressible flow about obstacles behind which are constant-pressure cavities of infinite extent.

Über die Temperaturverteilung hinter angeströmten Zylindern. J. Ackeret. *ETH Inst. für Aerodynamik (Zurich), Mitteilungen 21*, 1954, pp. 5–17. In German. On the temperature distribution behind cylinders.

A Vortical Singularity in Conical Flow. M. Holt. *Quart. J. Mech. & Appl. Math.*, Dec., 1954, pp. 438–445. Analysis of the singular line of Ferri in supersonic flow past a yawed cone.

Water Waves Generated by Oscillating Bodies. F. Ursell. *Quart. J. Mech. &*

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1N137B	20	.03 at 20V	5 at 20V	36
1N138B	40	.01 at 10V	2 at 10V	18
1N350	20	.03 at 60V	5 at 60V	70
1N351	8	.03 at 100V	5 at 100V	120
1N352	5	.05 at 150V	10 at 150V	170
1N353	3	.10 at 200V	20 at 200V	225
1N354	1	.10 at 300V	20 at 300V	325

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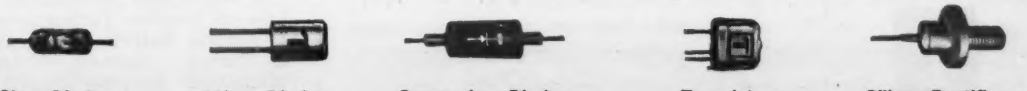

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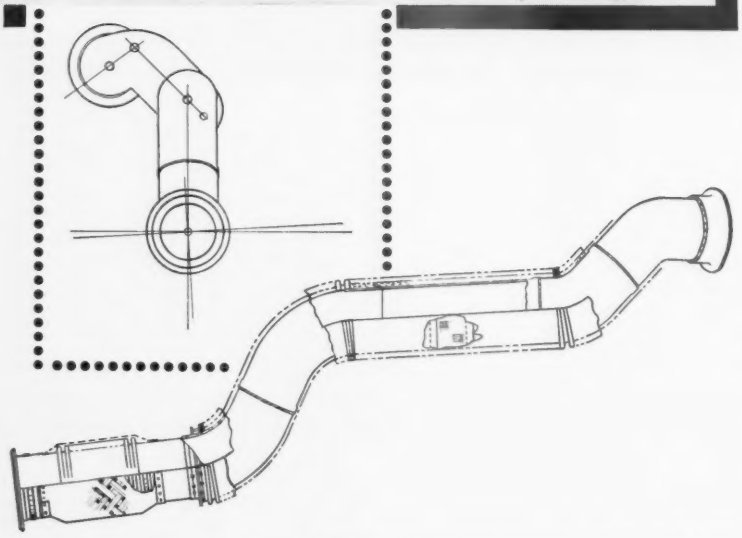

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Appl. Math., Dec., 1954, pp. 427–437. 12 refs. Analysis for the case of a two-dimensional wave motion in an ideal fluid under gravity by an infinitely long cylinder with horizontal generators oscillating vertically with constant frequency and small amplitude.

Internal Flow

An Accurate and Rapid Method for the Design of Supersonic Nozzles. Ivan E. Beckwith and John A. Moore. *U.S., NACA TN 3322*, Feb., 1955. 57 pp. 10 refs. Development of a procedure to compute streamline coordinates from tabulated flow parameters, with the method of characteristics used to obtain the first part of the flow consisting of a continuous expansion from a uniform sonic flow to a radial flow.

An Approximate Method of Calculating Three-Dimensional, Compressible Flow in Axial Turbo-machines. Carl O. Holmquist and W. Duncan Rannie. *IAS 23rd Annual Meeting, New York, Jan. 24–27, 1955, Paper.* 46 pp. 15 refs.

A Correlation of the Resistance to Air Flow of Wire Gauzes. P. Grootenhuis. *IME Proc.*, No. 34, 1954, pp. 837–843; Communications, pp. 843–845; Author's reply, pp. 845, 846. 29 refs. Analysis at Reynolds Numbers of 0.1–5,000 analogous to flow through passages or pipes, with the resistance being due mainly to the friction between the flow and the surfaces of the voids in the gauze.

Dynamiczna Teoria Zjawiska Pompowania w Sprężarkach Wirnikowych (Dynamic Theory of the Phenomenon of Compressor Surge). Robert Szewalski. *Arch. Budowy Maszyn* (Warsaw), No. 4, 1954, pp. 375–388. In Polish, with summaries in English and Russian.

An Evaluation of Non-Newtonian Flow in Pipe Lines. Ruth N. Weltmann. *U.S., NACA TN 3397*, Feb., 1955. 40 pp. 16 refs. Analytical method to determine pressure losses due to the flow of non-Newtonian materials in pipe lines using basic data from measurements of flow rate-of-shear shearing-stress curves.

Experiments on Turbulent Flow Through Channels Having Porous Rough Surfaces with or Without Air Injection. E. R. G. Eckert, Anthony J. Diaguila, and Patrick L. Donoughe. *U.S., NACA TN 3339*, Feb., 1955. 45 pp. 12 refs.

The Flow of Air Through Radial Labyrinth Glands. W. J. Kearton. *Chartered Mech. Engr.*, Feb., 1955, pp. 109–111. Abridged.

Ingestion of Foreign Objects into Turbine Engines by Vortices. Lewis A. Rodert and Floyd B. Garrett. *U.S., NACA TN 3330*, Feb., 1955. 23 pp.

On Unsteady Flow Through a Cascade of Aerofoils. L. C. Woods. *Proc. Royal Soc. (London), Ser. A*, Feb. 15, 1955, pp. 50–65. 14 refs. Development of a basic theory of two-dimensional flow, with expressions for the pressure distribution, lift, and moment on an airfoil of the cascade.

A Wind-tunnel Investigation of Entry Loss on Propeller Turbine Installations. I—Annular Entries Behind Propellers. II—Ducted Spinners. Appendix—Method of Analysing Ducted Spinner Loss. J. Seddon and A. Spence. *Gt. Brit., ARC R&M 2894* (Aug., 1948).

1954. 56 pp. BIS, New York. $3.40. Analysis for direct-flow engines using axial compressors, with the air taken in at an annular entry directly behind the rotating propeller and spinner as compared with test results on ducted spinners.

Stability & Control

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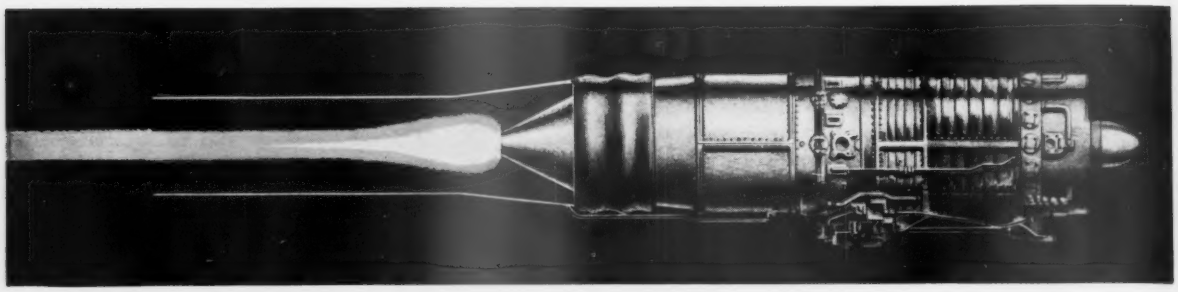

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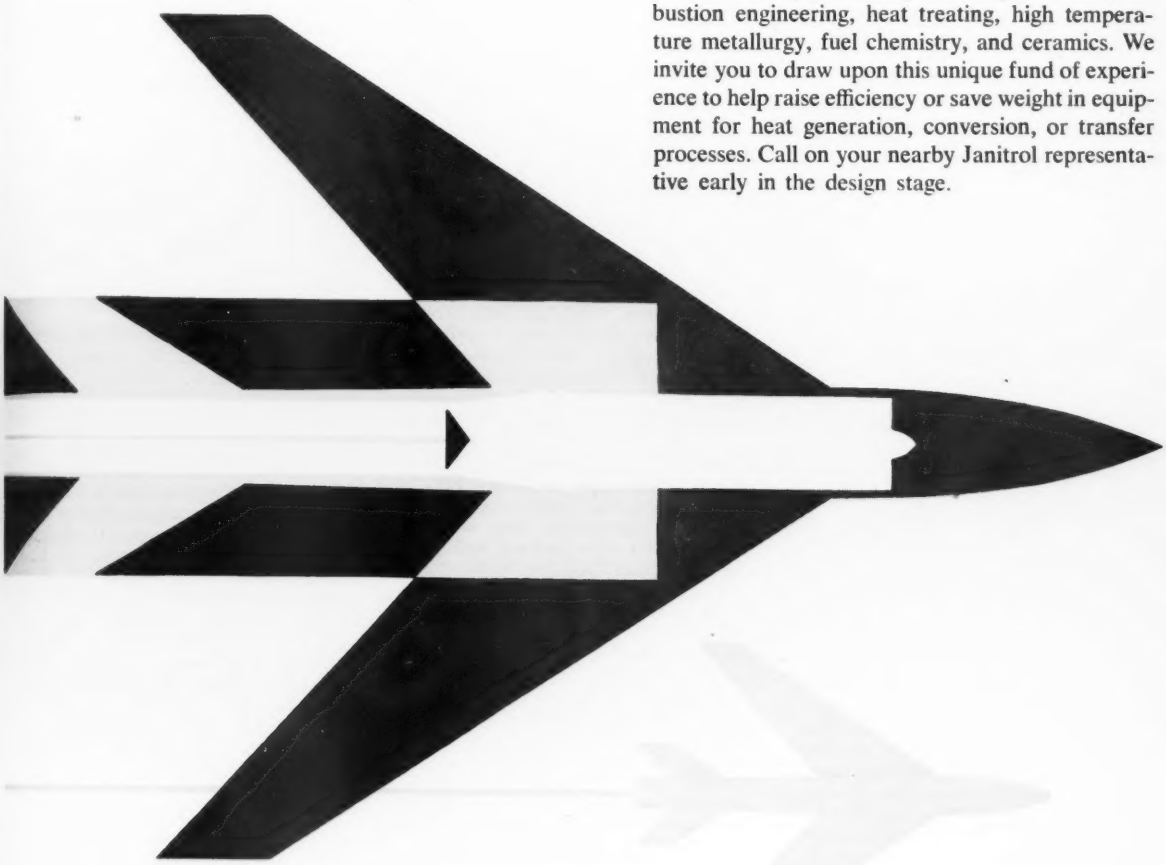

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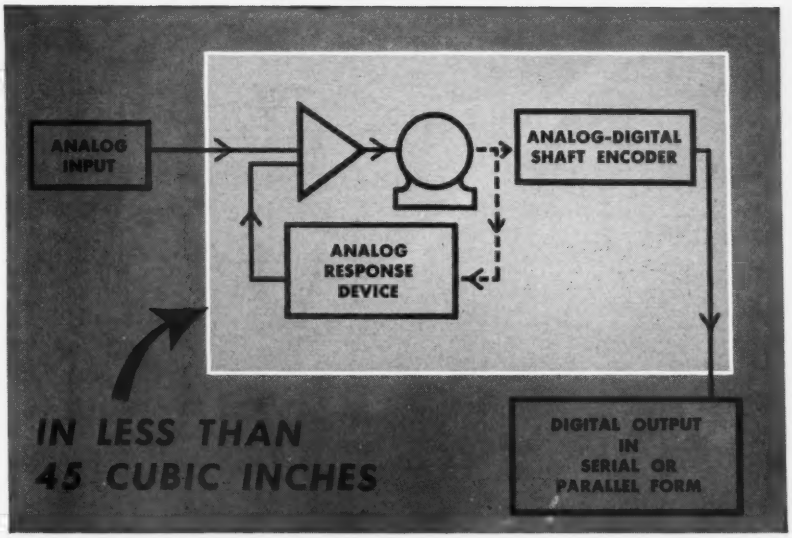
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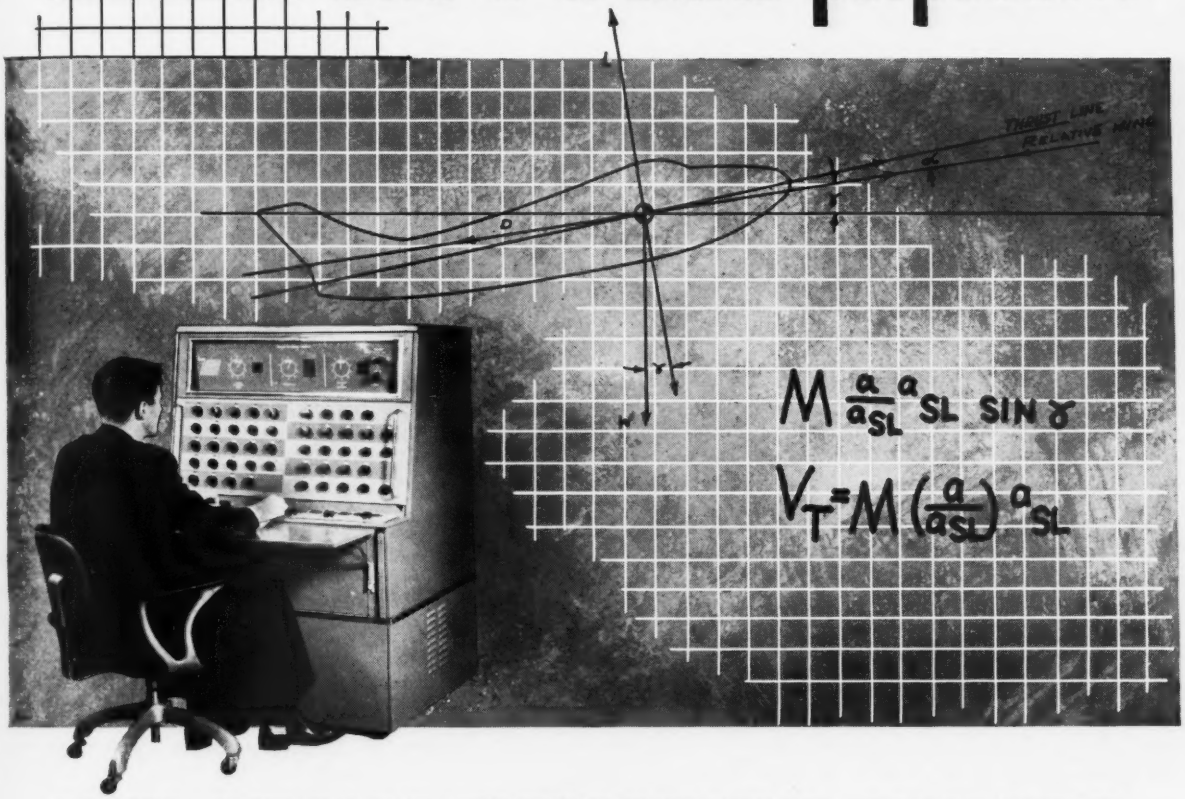

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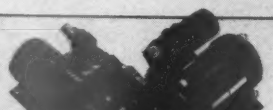

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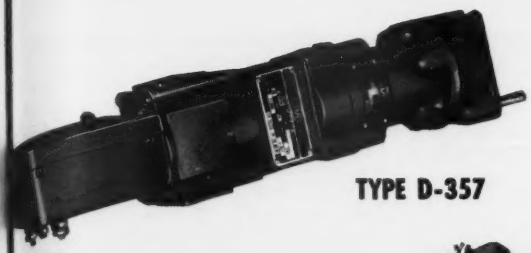

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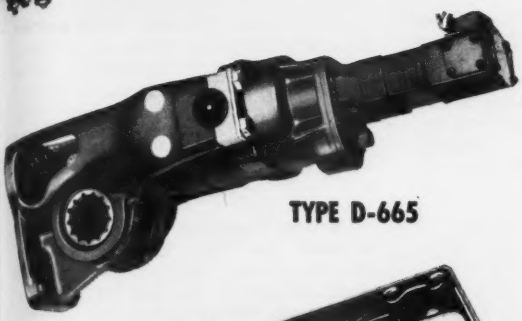

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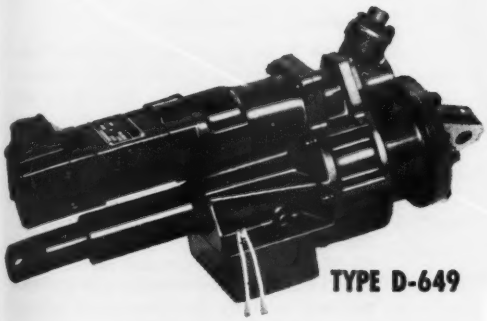

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TYPE D-357: EEMCO-designed canopy actuator develops 50 inch-pounds at 280 r.p.m. operating on 28 volts D.C. in intermittent duty. Gear ratio is 40 to 1. Unit includes magnetic clutch and brake and radio noise filter. Stall torque is 300 inch-pounds maximum. Weight: 4¾ lbs.

TYPE D-665: Designed as a trailing edge actuator for jet fighters. It has a normal peak load of 28,000 inch-pounds and a total angular travel of 30°. Speed is .675 r.p.m. with an average load of 14,000 inch-pounds on a 28 volt D.C. system (18.75 amps). Ultimate static load is 77,000 inch-pounds. Weight: 25½ lbs. Design incorporates auxiliary power take-off and non-jamming end stops.

TYPE D-471: Flexible universal rotary power package combines in one small container: motor, radio noise filter, magnetic clutch and brake, main reduction gear and auxiliary gears for driving adjustable limit switches, light switches and position indicator. It has a wide variety of possible adaptations utilizing flexible shafting to drive small rotary or linear actuators singly or in multiples. Dimensions are only 7⅛" x 4-7/16" x 2¾". Weight: only 3⅜ lbs. Specifications may be varied to suit special requirements.

LINEAR ACTUATORS

TYPE D-649: This rugged linear actuator weighs 13¾ lbs., and operates with a stroke of 3-5/16" at .55 inch per second under a working load of 3400 lbs. normal tension and 8200 lbs. peak tension on a 28 volt D.C. system. Maximum static load is 18,750 lbs. It has a flexible shaft drive take-off, load limit switches, non-jamming end stops and a retraction stop that adjusts to within ¼ inch. With minimum expense and delivery time EEMCO's Type D-649 can be supplied for various loads, lengths of stroke, rates of travel and other characteristics.

TYPE R-149: This unique linear actuator is entirely self-contained; the motor, clutch, planetary reduction gear and limit switch are all enclosed within the smaller inner cylinder. Type R-149 has an unusually long stroke of 9.625" at .3" per second under a normal load of 4000 lbs. on a 28 volt D.C. system. Maximum operating load is 8000 lbs., maximum static load, 15,000 lbs. Compact Type R-149 has adjustable load limit switches, non-jamming end stops, and a motor that shuts off automatically when end stops are reached, or load exceeds a pre-set limit. Weight: 10 lbs., 5 oz.

PROJECT ENGINEERS ***Please Note!***

EEMCO has designed, developed, tested and manufactured scores of motor and actuator models of various sizes, capacities and specifications. Perhaps one of these can solve a problem that now confronts you. Use of it might save precious design, development and testing expense and delivery time. In fact, even modification of a present EEMCO model could save considerable time and money versus establishment of a completely new unit that you now feel must be designed, developed and tested before production and delivery can begin.

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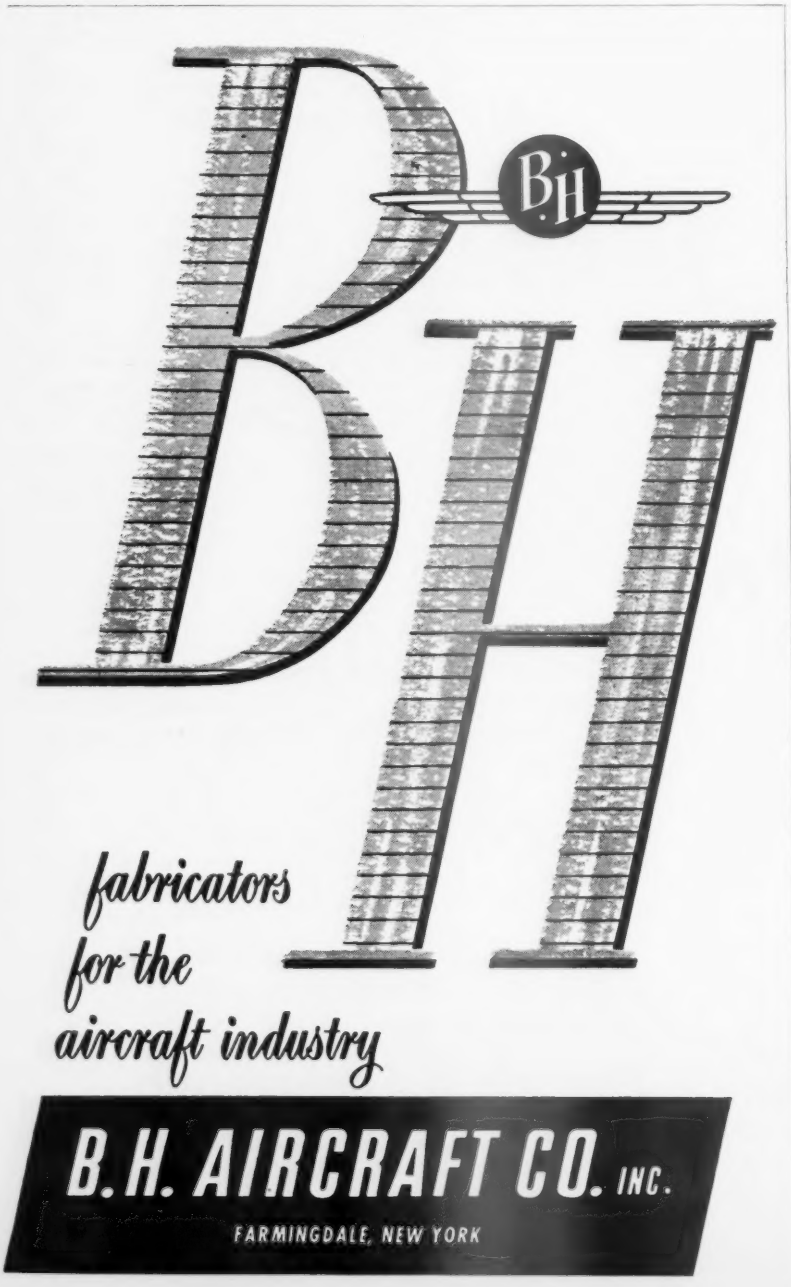

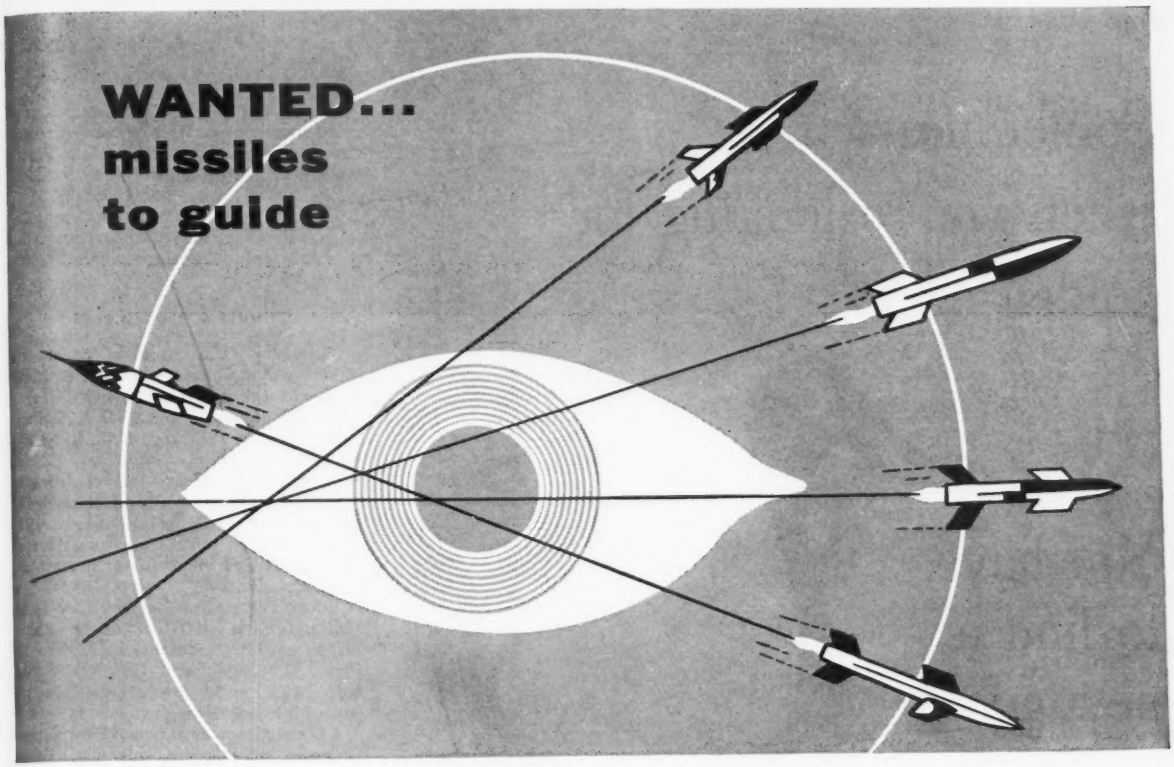

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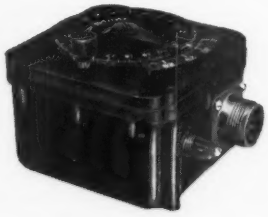

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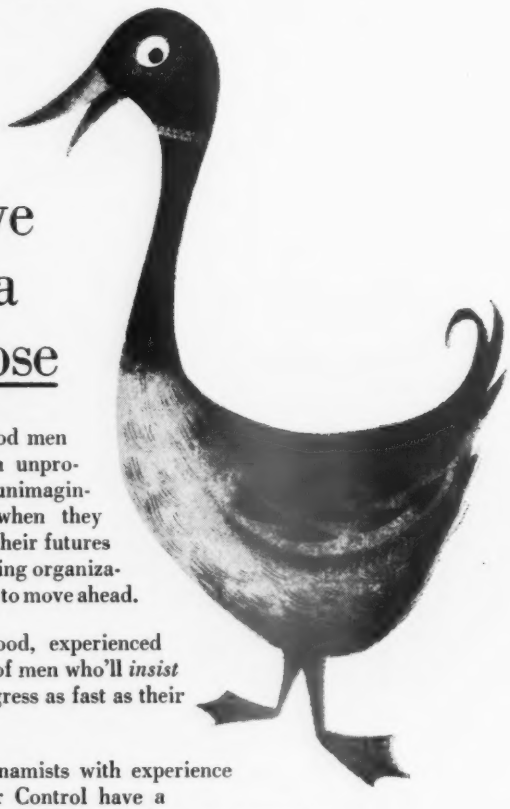

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Waldes Truarc ring reduces valve body from 1 5/16" to 1 1/16", eliminates chrome plating

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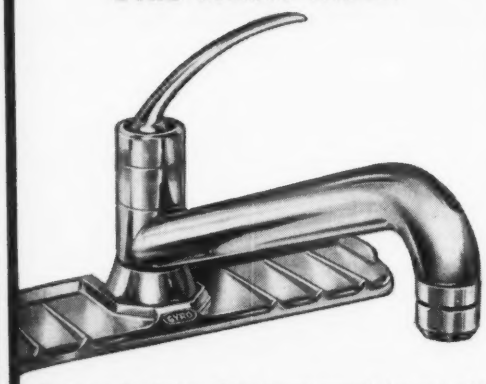

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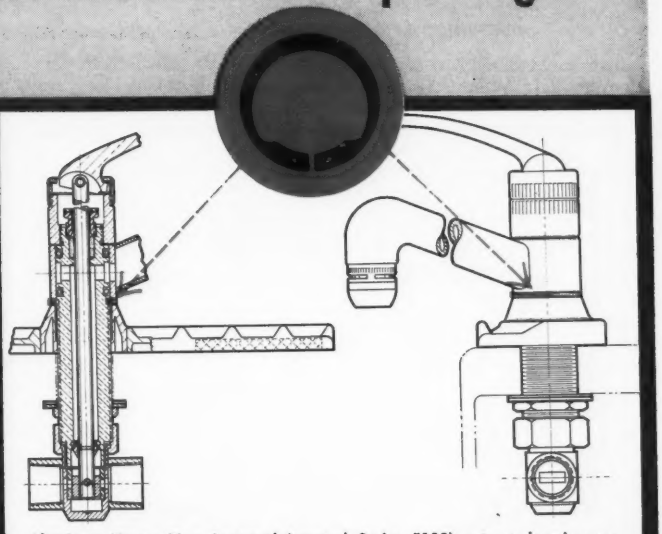

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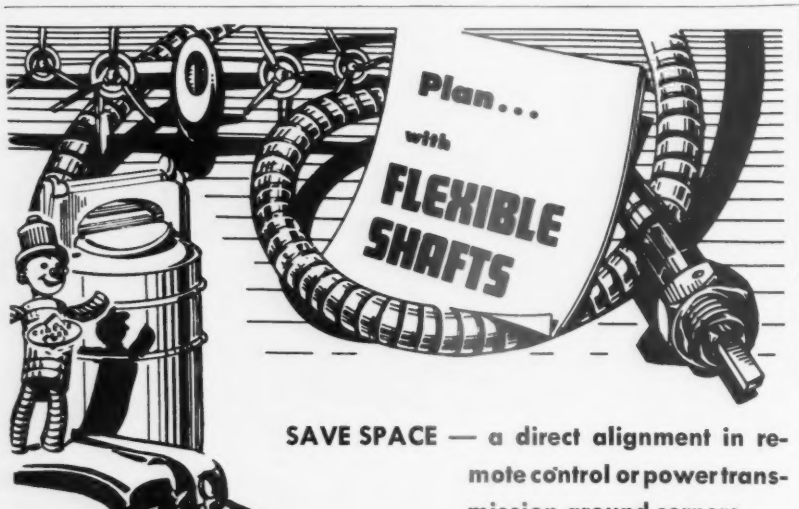

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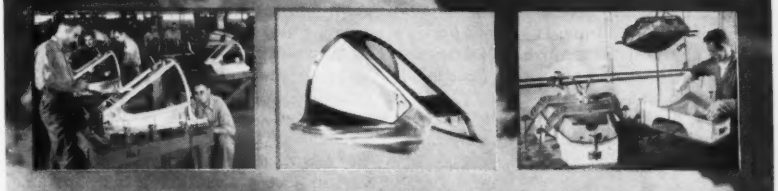

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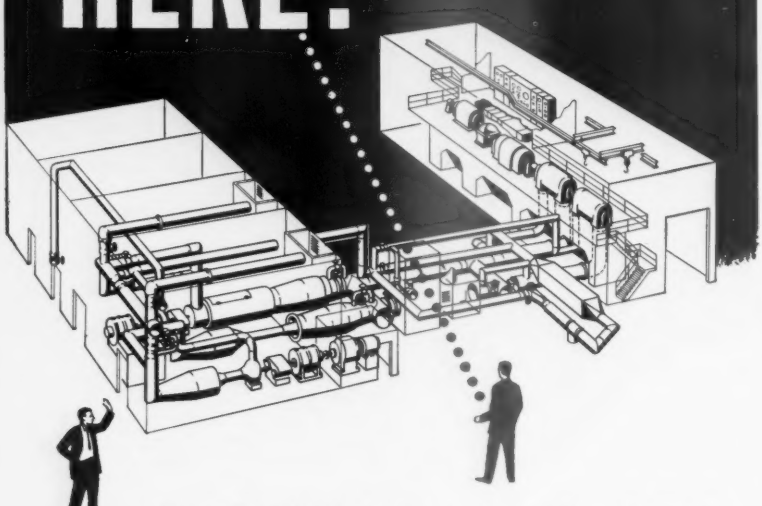

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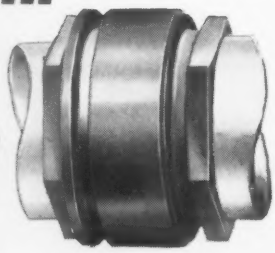

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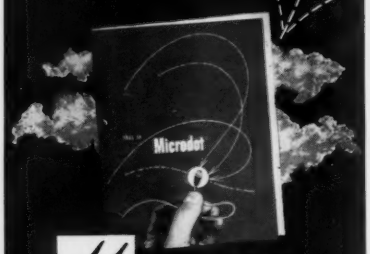

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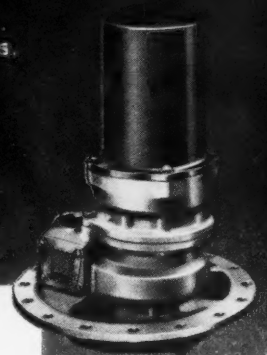

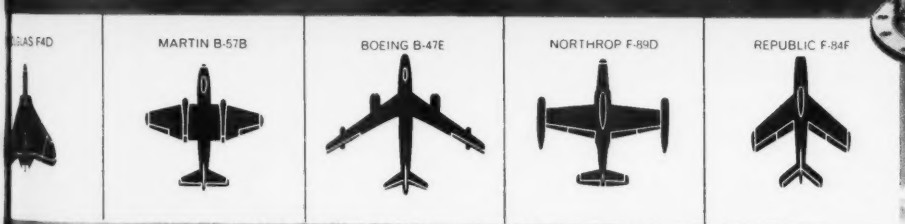

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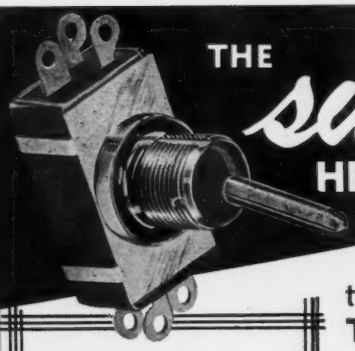

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A Thermal Equation for Flame Quenching. A. E. Potter, Jr., and A. L. Berlad. *U.S., NACA TN 3398*, Feb., 1955. 18 pp. 17 refs. Derivation of an approximate equation for quenching distance based on a diffusional concept and expressed in terms of the thermal conductivity, fuel mole fraction, heat capacity, rate of the rate-controlling chemical reactions, a constant that depends on the geometry of the quenching surface, and one empirical constant.

Heat Transfer

An Analysis of Turbulent Free-Convection Heat-Transfer. F. J. Bayley. *Chartered Mech. Engr.*, Feb., 1955, pp. 106, 107. Abridged.

Conduction of Fluctuating Heat Flow in a Wall Consisting of Many Layers. Václav Vodička. *Appl. Sci. Res., Sect. A*, No. 2–3, 1955, pp. 108–120.

Heat Waves in Multilayer Cylindrical Bodies. Václav Vodička. *Appl. Sci. Res., Sect. A*, No. 2–3, 1955, pp. 115–120.

Kinetic Theory of Evaporation Rates of Liquids. Eric F. Lype. *Trans. ASME*, Feb., 1955, pp. 211–219; Discussion, pp. 219–223. 30 refs. Analytical heat-transfer calculations based on the Polanyi-Wigner theory of the escape of molecules from the surface of a solid body as extended by Volmer.

Measured Effective Thermal Conductivity of Uranium Oxide Powder in Various Gases and Gas Mixtures. J. S. Boegli and R. G. Deissler. *U.S., NACA RM E54L10*, Mar. 3, 1955. 20 pp.

On the Start of Nucleation in Boiling Heat Transfer. R. H. Sabersky and C. W. Gates, Jr. *Jet Propulsion*, Feb., 1955, pp. 67–70.

Some Measurements of Boiling Burn-Out. Warren H. Lowdermilk and Walter F. Weiland. *U.S., NACA RM E54K10*, Feb. 23, 1955. 17 pp. Experimental investigation of boiling burn-out heat flux for water flowing upward through an electrically heated tube of an open-cycle flow system for: velocity range of 0.1–19 ft. per sec.; pressure from atmospheric to 2,000 lb. per sq. in.; length-diameter ratios of 25, 37.5, and 50; and inlet subcooling between 0° and 400° F.

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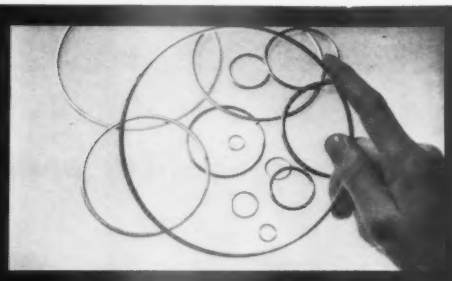

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Über thermische Effekte in Resonanzrohren (On Thermal Effects with Resonance Tubes). Herbert Sprenger. *ETH Inst. für Aerodynamik (Zurich), Mitteilungen 21*, 1954, pp. 18–35. 11 refs. In German.

Wind Tunnels & Research Facilities

An Angle-of-Attack and Angle-of-Yaw Indicator Using a Direct-Reading, Simple Strain-Gauge Circuit on Sting Balances. Robert B. Ormsby, Jr. *U.S., Navy Dept., David W. Taylor Model Basin, Rep. 885*, Feb., 1954. 17 pp. Development for direct supersonic wind-tunnel measurements to replace pendulum devices that will not work in the yaw plane.

The Design and Testing of Supersonic Flutter Models. John F. McCarthy, Jr., and Robert L. Halfman. *IAS 23rd Annual Meeting, New York, Jan. 24–27, 1955, Preprint 513.* 11 pp. Members, $0.35; nonmembers, $0.75. Review of the construction and requirements of wind-tunnel models for simulating full-scale airplanes at 1.2–2.1 Mach Numbers, with techniques of vibration, static, and flutter testing under varying flow parameters in the MIT Blowdown Wind Tunnel.

Generalization of Gas-Flow-Interferometry Theory and Interferogram Evaluation Equations for One-Dimensional Density Field. Walton L. Howes and Donald R. Buchele. *U.S., NACA TN 3340*, Feb., 1955. 70 pp. 18 refs. Theoretical and experimental development of a research technique; applications.

Some Measurements of Time and Space Correlation in Wind Tunnel. A. Favre, J. Gaviglio, and R. Dumas. (*La Recherche Aéronautique*, Mar.-Apr., 1953, pp. 21–28.) *U.S., NACA TM 1370*, Feb., 1955. 21 pp. 19 refs. Translation. Spectral analyzers and measuring instruments for statistical correlation in longitudinal time and space of turbulent speeds; applications include study of the case of a flat-plate boundary layer.

Wind Tunnels, Miscellaneous; First Impressions of N.A.E., Bedford: Farnborough Facilities Reviewed. *Flight*, Feb. 25, 1955, pp. 229–232, cutaway drawing. Descriptive details of layout designs, apparatus, and instrumentation.

Evaluating Shock Mounts. J. P. Walsh and R. E. Blake. *Mech. Eng.*, Mar., 1955, pp. 231–235. NRL experimental equipment and test procedures to study shock motions and spectra and vibrational frequencies.

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Book Notes

COMPUTERS

Diagrams in Punched Card Computing. Fred Gruenberger. Madison, University of Wisconsin Press, 1954. 139 pp., illus., diagrs., figs. $3.75.

The diagrams in this book show some of the things that can be done with basic equipment. Some of the panels and principles apply directly to routine work; others illustrate what might well be done. The text material is the outgrowth of a series of seminar talks by the author.

ELECTRONICS & ELECTRICITY

Transistors: Theory and Application. Abraham Coblenz and Harry L. Owens. New York, McGraw-Hill Book Company, Inc., 1955. 313 pp., illus., diagrs., figs. $6.00.

The book covers the theory of transistors from the vantage point of the electronics technician or engineer and includes those aspects of transistor manufacture which have a bearing on transistor characteristics and applications. The theoretical matter is presented with a minimum of mathematics and with pronounced emphasis on the applications to working circuits. It is intended for technicians of all grades who are in the electronics field and whose mathematical preparation may be limited. Mathematical analyses that were felt to be essential to a complete presentation, such as those in Chapter 12, Cascading of Resistors, may be omitted, restricting the reading to the commentaries. Mr. Coblenz is with Transistor Products, Inc., and was formerly with the Signal Corps Engineering Laboratories where Owens is now associated.

Contents: A Short History of Transistors. Holes and the Transistor. A Glimpse of Quantum Mechanics. The Electron. Nature of Semiconductors. Point Contact Transistors. Junction Transistors. Electronics of Transistors. Small-Signal Parameters. Grounded Emitter and Grounded Collector Connections. Theory of Transistor Switching Circuits. Cascading of Transistors. Manufacturing Processes. Silicon. Special Topics.

Transistor Audio Amplifiers. Richard F. Shea. New York, John Wiley & Sons, Inc., 1955. 219 pp., diagrs., figs. $6.50.

The primary purpose of this book is to provide the practical fundamentals of transistor applications and to show how these fundamentals may be used in the construction of audio amplifiers. Employing only a minimum of mathematics, the author explains how the reader may (1) intelligently apply these principles in his designs, (2) avoid pitfalls, and (3) achieve the ultimate in performance from transistor devices. The treatment is general, and applicable to the great majority of specifications that are available from transistor manufacturers. Data are presented on the variation of transistor parameters with operating point, with temperature, and between units. Also, the various methods of coupling transistor stages together are analyzed. A number of examples are given of the design of amplifiers intended for a variety of applications, ranging from pre-amplifiers to relatively high-powered output amplifiers.

The volume should provide the reader with the necessary tools whereby he can design an audio amplifier to meet the prerequisites of frequency response, signal-to-noise ratio, input power, and output power in such a manner as to ensure maximum reproducibility, longest life, maximum freedom from the effects of temperature and humidity, and lowest cost. Mr. Shea is in charge of Research Liaison at the Laboratories Department of the General Electric Company.

Guide to Transistor Literature, 1954. Richard L. Young, Jr., and Ralph Steffens of the Electronics Department of The Martin Company. Baltimore, Presentations Section, Engineering Division of The Glenn L. Martin Company, 1954. 54 pp.

The transistor papers cited in this compilation number well over 400. These titles have seemed most pertinent to the work of the electronics engineer—for whom the bibliography is particularly intended. The entries have been classified under the following headings: Theory, Characteristics, Circuits, Types, Applications, Production & Testing, and General Information. A subject index has been included.

Transistors and Their Applications; A Bibliography, 1948–1953. Compiled under the Direction of Alan R. Krull. Evanston, Technological Institute Library of Northwestern University, 1954. 77 pp.

This bibliography contains over 800 references that have been compiled by students using the facilities of the Technological Institute Library. The references are arranged according to year and then alphabetically by author.

Investigation of Electron Tube Reliability in Military Applications. Aeronautical Radio, Inc., Contract Administered by Department of the Navy, Bureau of Ships. Washington, D.C., Aeronautical Radio, Inc., 1954. 97 pp., diagrs., figs. $0.50.

The report covers the period from April 4, 1951, through March 31, 1954, and describes the scope of the ARINC surveillance program, the methods of tube collection and of engineering and statistical analysis, and the results of the program to date. It contains a discussion of the characteristic defect patterns of tube returns from each of the eight military bases under surveillance and an analysis of each of the 20 individual tube types ranking highest in number of tubes returned. There is also an evaluation of tube weaknesses, supplemented by discussion of factors contributing to tube unreliability, such as environment, operating procedures, misapplications, and maintenance. Incorporated in the report are 65 tables, 24 charts, and a statistical appendix.

A Textbook of Radar; A Collective Work by the Staff of The Radiophysics Laboratory, C.S.I.R.O., Australia. Edited by E. G. Bowen. 2nd Ed. New York, Cambridge University Press, 1954. 617 pp., illus., diagrs., figs. $8.50.

In the first 512 pages all errors of the earlier edition have been corrected, and the references have been altered to cover published papers now readily obtainable. The last section has been rewritten to bring the account up to date. It includes material on the application of radar to astronomy, radar aids to surveying and to marine and air navigation, and the application to meteorology. The bibliography has also been brought up to date. The text book is suitable for graduate and research students and for engineers engaged in research and development in industry.

Noise. Aldert van der Ziel. New York, Prentice-Hall, Inc., 1954. 450 pp., diagrs., figs. $10.35.

This book is concerned with noise in electronic devices and reduces solutions to most noise problems to an analysis of simple networks. The various sources of noise in tubes and circuits are analyzed in Chapters 2 and 5–10. Methods of characterizing the noise in circuits and in circuit elements are given in Chapter 3, and a discussion of noise measurements is provided in Chapter 4. Chapters 11–15 discuss those noise problems that demand a more elaborate mathematical treatment than is required in the first part of the book. Chapter 11 deals with the laws of probability, statistics, and thermodynamics which are needed for problems in noise. Chapter 12 deals with the Fourier analysis of fluctuating quantities. Response of detector circuits to noise is treated in Chapter 13, and the laws of vacuum-tube electronics and electron wave tubes are considered in Chapters 14 and 15 respectively. A discussion of noise in physical measurements appears in Chapter 16. It is not the purpose of the author to deal with those noise problems encountered in information theory. The author is Professor of Electrical Engineering, University of Minnesota.

Magnetic Fields of Cylindrical Coils and Annular Coils. Chester Snow. (National Bureau of Standards, Applied Mathematics Series No. 38.) Washington, Superintendent of Documents, 1953. 29 pp., diagrs., figs. $0.25.

Mathematical formulas are developed in terms of complete elliptic integrals or of Legendre functions for the axial and radial components of the magnetic field produced by cylindrical coils carrying an electric current. Cases treated include cylindrical current sheet, circular current sheet (with circumferential flow of current), and multilayer solenoid.

Advances in Electronics and Electron Physics, Vol. 6. Edited by L. Marton. New York

For information on IAS Library Service Facilities, see page 153.

Statements and opinions expressed in Book Reviews are to be understood as individual expressions and not necessarily those of the Institute.

Academic Press Inc., 1954. 538 pp., illus., diagrs., figs. $11.80.

Contents: Metallic Conduction at High Frequencies and Low Temperatures, A. B. Pippard. Relaxation Processes in Ferromagnetism, Elihu Abrahams. Physical Properties of Ferrites, J. Smit and H. P. J. Wijn. Space Charge Limited Currents, Henry F. Ivey. A Comparison of Analogous Semiconductor and Gaseous Electronics Devices, W. M. Webster. The Electron Microscope—A Review, M. E. Haine. Traveling-Wave Tubes, Rudolf G. E. Hutter. Paramagnetism, J. Van den Handel. Author Index. Subject Index.

Electronics. Thomas B. Brown. New York, John Wiley & Sons, Inc., 1954. 545 pp., illus., diagrs., figs. $7.50.

A textbook for students in science and engineering which presents fundamental concepts and principles with emphasis on the physical interpretations of the phenomena studied. Liberal use is made of graphic methods, and the many laboratory experiments form an integral part of the book. The volume has been written to meet the needs of a basic course at George Washington University for students of physics, engineering, and other sciences.

Magnetic Amplifiers. H. F. Storm. New York, John Wiley & Sons, Inc., 1955. 545 pp., illus., diagrs., figs. $13.50.

This book by H. F. Storm and other specialists at the General Electric Company offers a useful presentation of the theory of magnetic amplifiers, along with theoretical and practical data on core materials, coremaking techniques, and metallic rectifiers. Many practical applications are described. Written on the graduate level, this book is concerned mosly with single-phase amplifiers. The treatment begins with the simplest form—the ordinary saturable reactor. From this beginning the reader progresses to the higher forms of magnetic amplifiers and finally arrives at the so-called self-saturated magnetic amplifier, also known as the amplistat or magamp.

Although the theory of the magnetic amplifier is the focal point of the book, related fields vitally affecting the performance of magnetic amplifiers are also discussed. This coverage includes: a modern theory of magnetism; characteristics of magnetic materials; magnetic testing; manufacture of saturable reactors; and properties of metallic rectifiers. Because of the close relation between magnetic amplifiers and a.c. saturating reactors, a complete chapter is given to peaking transformers, voltage stabilizers, nonlinear resonance circuits, and reactors for large mechanical rectifiers. The behavior of magnetic amplifiers is explained from fundamental physical principles, avoiding mathematical complexity. Magnetic amplifiers are also represented in servo-block diagram form, suitable for immediate integration into a servo system. The book also contains many significant references to domestic and foreign sources.

Magnetic Amplifiers. George M. Ettinger. New York, John Wiley & Sons, Inc., 1953. 88 pp., diagrs., figs. $1.50.

This small monograph is intended to serve the engineer or physicist in selecting a suitable device and to provide a starting point for the research worker who aims to make further advances in the field.

Contents: 1, Introduction. 2, Saturable Reactors. 3, Magnetic Amplifiers. 4, The Harmonic Type Magnetic Amplifier. 5, Ferro-Resonance. 6, Time Lag and Transient Response. 7, Saturating Core Elements for Computer Systems.

Storage Batteries; A General Treatise on the Physics and Chemistry of Secondary Batteries and their Engineering Applications. George Wood Vinal. 4th Ed. New York, John Wiley & Sons, Inc., 1955. 446 pp., illus., diagrs., figs. $10.

A thorough revision has been made to reflect the progress in the industry since 1940. Obsolete matter has been eliminated, and approximately half of the illustrations are new.

MATERIALS

Titanium in Industry; Technology of Structural Titanium. Stanley Abkowitz, John J. Burke, and Ralph H. Hitz, Jr. New York, D. Van Nostrand Company, Inc., 1955. 224 pp., illus., diagrs., figs. $5.00.

This survey of the status of titanium has been written to satisfy the demands of plant superintendents, shop foremen, and those who work with titanium. It is intended also as a guide for the production and process engineer and as a reference work for the research metallurgist. The coverage has been confined to titanium as a primary metal. Its use as an oxide or as an alloying element in other metals has been mentioned only where it adds to the completeness of the book. The various methods of obtaining the metal from its ores, and the physical, chemical, and mechanical properties of titanium and its alloys are included. There are chapters covering alloying and heat treatment, hot and cold shaping, casting and powder metallurgy, and joining, machining, and grinding. Surface properties, corrosion, coatings, hardening, and cleaning are covered as well as analytic and metallographic techniques. The final chapter, Selection of Materials and Applications, encompasses the uses of titanium in the aircraft field. Literature references at the ends of chapters and a combined subject and author index have been included by the authors, all three of whom are associated with the Watertown Arsenal Laboratory.

Titanium and Titanium Alloys. John L. Everhart. New York, Reinhold Publishing Corp., 1954. 184 pp., diagrs., figs. $3.00.

The purpose of this book is to present a selective review of work on titanium alloys which has been published in scientific and technical literature and in business publications. This review has been supplemented with information obtained from the producers of the commercial materials. This volume is intended almost exclusively for the engineer or designer who is interested in the possi-

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bilities of applying titanium to the solution of his problems.

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Titanium in Iron and Steel. George F. Comstock. New York, Published for The Engineering Foundation by John Wiley & Sons, Inc., 1955. 294 pp., illus., diagrs., figs. $6.00.

Titanium in Iron and Steel critically reviews and correlates the important data in world literature on titanium as an alloying element in iron and steel. Nearly 300 papers (listed in the bibliography at the end of the book) were reviewed for the manuscript. Opening with a general discussion of titanium and its minerals—principal sources, concentration, preparation, etc.—the book goes on to examine the properties and effects of the element as an addition to cast iron and steel. Its deoxidizing effects are discussed in full. Special emphasis is placed on titanium effects in stabilizing nitrogen and in fixing carbon in alloys where other carbides may be undesirable, on its usefulness in steel that is to be enamelled, and in certain complex ferrous alloys for high-temperature application. The author is Consultant to the Titanium Alloy Division of the National Lead Company.

Adhesion and Adhesives; Fundamentals and Practice. Papers read at a Symposium Held at Case Institute of Technology in Cleveland, Ohio, and a Conference Held in London, England. New York, John Wiley & Sons, Inc.; London, Society of Chemical Industry, 1954. 229 pp., illus., diagrs., figs. $9.75.

The papers contained in this volume are the contributions made to two conferences, one held in London, April 22–24, 1952, by the Society of Chemical Industry, and the other held in Cleveland, April 24, 25, 1952, by Case Institute of Technology. The symposium was sponsored by Case as part of a program initiated by the Air Research and Development Command of the United States Air Force for the Chemistry Group of the Fight Research Laboratory of the Wright Air Development Center under contract.

Partial contents: Survey of Adhesion and Types of Bonds Involved, Frank W. Reinhart. On the Theory of Adhesion, S. J. Czyzak. Some Possible Surface Factors Involved in Joint Strength, D. D. Eley. Adhesion of Organic Surface Coatings, Henry Grinsfelder. Work of Adhesion at Solid-Solid Interfaces, Harold M. Scholberg and Marshall R. Hatfield. Surface Forces of Solids as Affected by the Polarization Properties of Ions, W. A. Weyl. Energy of Adhesion, Molecular Forces and Adhesive Rupture, Gerard Kraus. The Relation Between Friction and Adhesion, D. Tabor. The Wetting of Solids by the Process of Direct Contact, J. F. T. Blott, R. I. Hughes, and L. A. Werrett. The Adhesion of High Polymers to Cellulose—A Résumé, A. D. McLaren. The Development of a Characteristic Constant for the Determination of the Adhesive Properties of High Polymers, Otto F. Hecht, Harold W. Coles, and Margaret M. Keeler. The Part Played by Fluids in Adhesion, W. G. Campbell. Intermolecular Forces and the Strength in Adhesive Joints, Charles Kemball. The Mechanism of Adhesion, J. J. Bikerman. Types and Uses of Adhesives, R. F. Blomquist. Adhesives for Glass, Luther L. Yeager. Selecting Glass Adhesives by Strength Testing, Frank Moser. Adhesion in Laminated Glass, Allan C. Waine. Behaviour of Adhesives in Strength Testing, G. W. Koehn. Pressure-Sensitive Adhesion, M. Gainsly and J. Daw. The Adhesion of Elastomeric Pressure-Sensitive Adhesives: Rate Processes, Willard M. Bright. Aircraft Structural Adhesives, T. J. Martin. Air Force Elastomer Adhesion Problems, J. H. Bernstein. Room-Temperature-Setting Adhesives for Metals and Plastics, H. A. Perry, Jr. A Review of Synthetic Adhesives with a Section on Recent Developments, P. L. Bramwyche. The Adhesion of Metals, G. W. Rowe. Joining Aluminum: A Summary of Present Practice, E. G. West. Non-Destructive Testing of Adhesives by Ultra-Sonic Waves, Albert G. H. Dietz. Microcalorimeter for the Measurement of Energies of Adhesion, Philip E. Berghausen. Comments on Adequacy and Limitations of Current Test Methods, Lucius Gilman.

MATHEMATICS

Higher Transcendental Functions, Vol. 3. Based, in Part, on Notes left by Harry Bateman, Late Professor of Mathematics, Theoretical Physics, and Aeronautics at the California Institute of Technology, and Compiled by the Staff of the Bateman Manuscript Project. New York, McGraw-Hill Book Company, Inc., 1955. 292 pp., diagrs., figs. $6.50.

This is the third and final volume of the three-volume work of reference on advanced mathematics which aims at providing an extensive compilation of practically all the "special functions"—solutions of a wide class of mathematically and physically relevant functional equations—found to be most useful in pure and applied mathematics. This volume contains material on automorphic functions including elliptic modular functions; Lamé, Lamé-Wangerin, and Mathieu functions; spheroidal and ellipsoidal wave functions; functioning occurring in number theory; and some miscellaneous functions such as Mittar-Leffler's function. There is also a chapter on generating functions with a list of those known.

Lectures on Partial Differential Equations. I. G. Petrovsky. Translated from the Russian by A. Shenitzer. New York, Interscience Publishers, Inc., 1954. 245 pp., diagrs., figs. $5.75.

The original Russian text from which this translation was prepared was completed in 1950 and grew out of a series of lectures given to students of

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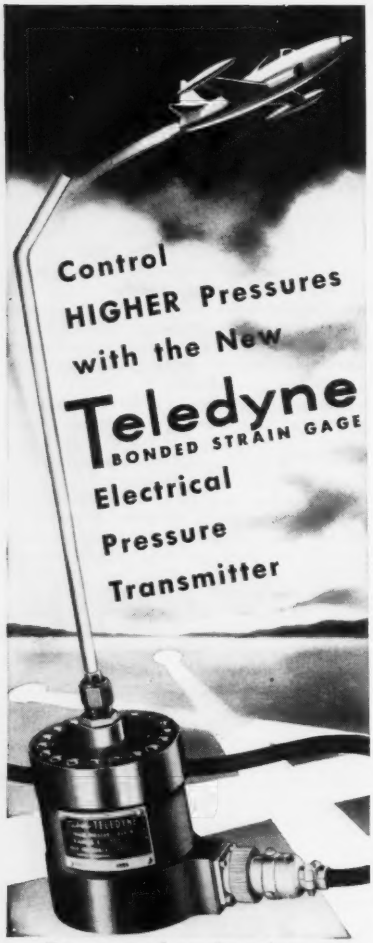

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mathematics at the Department of Mathematics and Mechanics of the Moscow State University.

Contents: I, Introduction, Classification of Equations. II, Hyperbolic Equations. III, Elliptic Equations. IV, Parabolic Equations.

Theory of Functions of a Complex Variable, Vol. 2. C. Caratheodory. Translated by F. Steinhart. New York, Chelsea Publishing Co., 1954. 220 pp., diagrs., figs. $4.50.

The German edition from which this translation has been made was published in 1950 in Switzerland. In keeping with the character of the whole work, the second volume stresses the geometric point of view even more than does the first. The present volume contains parts 6 and 7 of the entire work. The first of these two parts is devoted to the foundations of geometric function theory, and its three chapters deal with bounded functions and with conformal mapping. The second part deals with the triangle functions and Piccard's theorem.

POWER PLANTS

1954 Aircraft Spark Plug and Ignition Conference Report; Toledo, Ohio, October 5-7, 1954. Sponsored by Champion Spark Plug Co., Toledo, Ohio, 1954. 190 pp., diagrs., figs.

Among the topics discussed at the conference were spark plug fouling; effective fuels and lubricants on spark plugs; research and development; ignition analyzers; magnetos, harnesses, and leads; and jet ignition. The appendixes include a paper on ignition by J. G. Sharp and a paper by F. W. Lamb on "Postulated Mechanism of Spark Plug Fouling." There is a detailed subject index.

The Aircraft Magneto. Scintilla Magneto Division, Bendix Aviation Corp. 6th Ed. Sidney, N.Y., Scintilla Magneto Division, Bendix Aviation Corp., 1954. 61 pp., illus., diagrs., figs.

The object of this booklet is to describe the fundamental operating theory of high-tension and low-tension ignition systems.

SERVOMECHANISMS

Servomechanism Practice. William R. Ahrendt. New York, McGraw-Hill Book Company, Inc., 1954. 349 pp., illus., diagrs., figs. $7.00.

This book developed from a need to supplement the theory in a college course on servomechanisms with material on circuitry, electrical and mechanical components, and practical problems encountered in servo design and manufacture. Actual design procedure used for servomechanisms is described. Particularly stressed are the departures from idealization of the various components and what can be done about them to achieve the limit of their performance. Component values are given in the circuit diagrams, and tables of characteristics of typical components are also presented. Problems and questions accompany each chapter. The author is President, Ahrendt Instrument Company, and Lecturer, University of Maryland.

SOUND

Sonics; Techniques for the Use of Sound and Ultrasound in Engineering and Science. Theodor F. Hueter and Richard H. Bolt. New York, John Wiley & Sons, Inc., 1954. 456 pp., illus., diagrs., figs. $10.

The name sonics is used to designate the analysis, testing, and processing of materials and products by the use of mechanical vibratory energy. The underlying physics is presented as simply as possible, with plausibility arguments frequently used in place of rigorous derivations. Wherever possible a discussion is concluded with simplified engineering formulas and practical instructions for their application. This book also takes account of recent work done in England, Germany, and France. The authors are associated with the Massachusetts Institute of Technology.

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STRUCTURES

Minimum Weight Analysis; A Literature Review. George Gerard. New York, Research Division, College of Engineering of New York University, 1954. 15 pp.

A review of published literature on the minimum weight analysis of aircraft structures subject to buckling. The 44 references in the bibliography are listed chronologically, but the contributions of the individual papers are discussed under certain natural divisions of the overall subject. The references cover the years from 1942 to 1954, although there is one reference to a publication issued in 1929.

TELEMETERING

National Telemetering Conference, 1954; The Complete Papers and Discussions of the Conference Held at Chicago, May 24-26, 1954. Sponsored by the Institute of Radio Engineers, the Instrument Society of America, the Institute of the Aeronautical Sciences, and the American Institute of Electrical Engineers. New York, 1955. 179 pp., illus., diagrs., figs. $2.00. Available from the Institute of the Aeronautical Sciences, 2 East 64th Street, New York 21, N.Y., and also from the other sponsoring organizations.

Contents: Telemetering Systems: An Approach to Microwave Telemetering, Robert G. Rullman. An Eighteen-Band Research and Development Type of Telemetering System for Guided-Missile Use, J. F. Koukol. A Transistorized FM/FM Telemetering System, R. E. Colander and C. M. Kortman. Selective Telemetering Application, Leonard G. Walker and Dayton N. McMillan. Telemetering on the Illinois-Missouri Electric Power Pool, G. W. Fox, D. F. Hazen, H. E. Stites, W. S. Bloor, and T. W. Hissey. Recorder Computing Techniques Used in the Measurement and Telemetering of Electric Power and Associated Quantities, W. E. Phillips.

Telemetering Pickups and Components: Application of Transistors to Telemetering Components, C. M. Kortman. A Crystal Control FM Telemetry Transmitter, Foster N. Reynolds. A New Panoramic Instrument for Analyzing and Calibrating FM/FM Telemetering Systems, William I. L. Wu. New High Stability Component Configurations Solve Telemetering System Design Problems, L. A. G. ter Veen. The Movable Core Transformer as a Pickup for Industrial Telemetering Systems, A. J. Hornfeck and L. M. Wermelskirchen. Performance and Application of a Low Noise RF Pre-Amplifier and Multicoupler for Radio Telemetry, Garth E. Bower.

Workshop Session: Classification of Telemetering Systems, E. E. Lynch and W. J. Mayo-Wells.

Remote Control-Digital: An Electronic System for Air Traffic Control Information (Abstract), R. M. Kalb. Some Fundamental Capabilities and Limitations of Sampled-Data Systems, William K. Linvill. Remote Shaft Positioning Via Frequency Code Data Transmission Systems, E. A. Ragland. Centralized Supervisory Control of Pipelines by Microwave Communications, P. J. Brewster, E. P. Lounsberry, and J. B. Williams.

Remote Control-Analogue: Application of Analogue Computers to Sampling Control Systems (Title Only), H. Meissenger and A. Karen. Automatic Helicopter Positioning Through Past and Future Gyropilot Control, Jens Grano. The Application of Raydist to Remote Helicopter Control, J. T. Bradbury and A. L. Comstock. A Damper Stabilized Servo Data Repeater, John E. Ward.

All Weather Flight Control: Telemetering and Control for Civil Air Transports, David S. Little. Telemetering: The Missing Links in Today's Airway System, Arthur E. Jenks. Operational Telemetering, an Aid to Air Navigation, M. V. Kiebert, Jr.

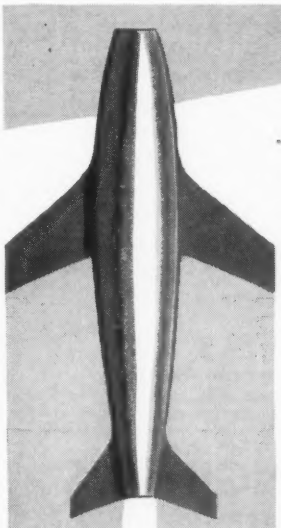
Information Handling-Data Reduction: Problems in Telemetry Data Reduction, D. Belloff. Cost Reduction in Data Reduction (Abstract), D. B. Prell. Telemetering Data Handling at AFFTC. Jerome J. Dover. A Digital Data-Recorder for Dense Storage of Continuous Voltages, Gerhard L. Hollander. A System for Recording and Analyzing Aircraft Flight Data, R. E. Colander and David Evans. A Survey of Data Processing Equipment for PWM-FM Telemetry, F. E. Bryan.

THERMODYNAMICS

Principles of Engineering Thermodynamics. Paul J. Keifer, Gilbert Ford Kinney, and Milton C. Stuart. 2nd Ed. New York, John Wiley & Sons, Inc., 1954. 539 pp., diagrs., figs. $7.75.

This book has been completely revised since publication of the first edition in 1930. The emphasis is on the principles of engineering thermodynamics, and it is endeavored to implant a recognition of both the ideal capabilities and the inherent limitations of power plants and similar equipment. The book provides a concise and effective presentation specifically designed to serve the requirements of the engineer. It covers the thermodynamic basis of fluid mechanics and aerodynamics and unifies the mechanical, chemical, and aerodynamic applications in a manner that is up to date and directly applicable to current engineering practice. A new type of float chart is introduced which, along with the convenience provided by the use of the Mach Number, greatly facilitates the study of the thermodynamics of compressible flow. A further innovation is the development of simple but valid means for accounting for the variation of the specific heats of gases with temperature. The earlier material relating to the mass and energy accounting in combustion processes is now supplemented by attention to the cause and consequences of the chemical equilibrium encountered in combustion processes at elevated temperatures. The first two authors are Professors at the U.S.

(*Continued on page 206*)



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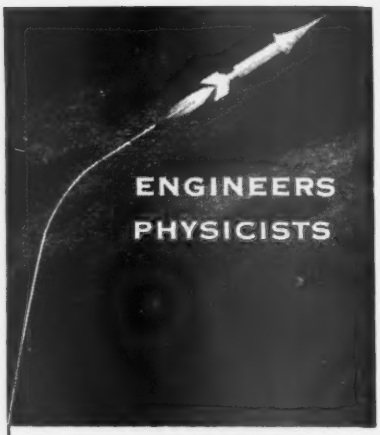

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Personnel Opportunities

This section is for the use of individual members of the Institute seeking new connections and organizations offering employment to Aeronautical specialists. Any member or organization may have requirements listed without charge by writing to the Secretary of the Institute.

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Preliminary Design Engineers—Foremost developer of emergency escape equipment has immediate need for preliminary design engineers, both structural and mechanical. Unlimited opportunities with young expanding organization. B.S. degree and minimum of 8 years' aircraft experience desired. Send résumé to: Administrative Engineer, Stanley Aviation Corporation, 2500 Dallas St., Denver 8, Colo.

Research Engineers—Aeroelastic and Structures Research Laboratory, Massachusetts Institute of Technology, offers staff positions to Research Engineers in the fields of aeroelasticity, structures, aerodynamics, plasticity, and thermoelasticity. Graduate study and research can be combined at salaries commensurate with experience. Send résumé to: Aeroelastic and Structures Research Laboratory, M.I.T., Cambridge 39, Mass.

Engineers and Scientists—Guided Missiles Division, Republic Aviation Corporation located at Hicksville, Long Island, New York. Openings exist for men (or women) with experience in the field of guided missiles and aircraft for design of air-borne instruments and analyses of control systems utilizing advanced mathematical, simulation and/or analog computer techniques. Positions also available in preliminary design and development work to assist in the preparation of weapons systems proposals. Address résumé to: R. Reissig, Administrative Engineer.

Engineers—Fairchild Engine Division of the Fairchild Engine and Airplane Corporation, Farmingdale, Long Island, New York. Diversified engineering positions are available involving engine design, covering both full scale and components, stress and vibration analysis, test engineering, field engineering, and other engineering operations associated with the general field of design and development of gas-turbine power plants. Send résumé to: Felix Gardner, Fairchild Engine Division, Farmingdale, Long Island, N.Y.

Assistant Professor—To teach dynamics, fluid mechanics, vibrations, and engineering analysis. At least a Master's degree and some industrial experience preferred. Apply to: Louis Slegel, Department of Mechanical Engineering, Oregon State College, Corvallis, Ore.

Engineers—Bendix Products Division at South Bend, Indiana, pioneer and leader in the research, design, development, and production of aircraft jet-engine control and landing gear systems, has continuing opportunity in a variety of assignments on interesting, long-range projects. Engineers needed in this organization, with a growth tradition, who have 2 to 5 years of experience in hydraulics, propulsion systems, servomechanisms, electromechanical design, aircraft controls, fluid mechanics, computers, fuel control systems, and liquid propellants. Many other engineering opportunities for Aeronautical, Mechanical and Electrical Engineers. Please send résumé outlining education, experience, and salary level to: Technical Placement, Employment Department, Bendix Products Division, Bendix Aviation Corporation, South Bend 20, Ind.

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The number preceding the notice represents the Box Number of the Institute of the Aeronautical Sciences to which inquiries should be addressed.

Engineers—Gas Turbine and Afterburner Engineers—Solar Aircraft Company in San Diego, California, has several immediate openings which represent outstanding opportunities for qualified engineers. The company has been designing, developing, and producing afterburners and small gas turbine engines for several years and recently has received new contracts—both for new development and production—which make necessary considerable expansion of the engineering staff. Needed are experienced **Mechanical Design Engineers,** for designing complete engines and components, **Experimental Engineers,** capable of directing development testing programs, **Jet Engine Analysts,** with thermo- and/or aerodynamic backgrounds for analyzing engine cycles and performance in various flight regimes, and **Electro-Mechanical Engineers,** with experience in hydraulic, pneumatic and electrical fields to do design work on gas turbine and afterburner controls. Send résumé of experience to: P. M. Klauber, Chief Administrative Engineer, Solar Aircraft Company, San Diego 12, Calif.

Hydraulics Engineer—Flight Refueling, Inc., a progressive and expanding company specializing in the pressure fuel systems field, needs a mechanical or aeronautical engineer with several years' experience in design and/or applications of hydraulic power components, and good overall knowledge of aircraft systems. Will function as a specialist, working on both research and development and project assignments. Apply by letter, to Employment Section, Flight Refueling, Inc., Box 1701, Baltimore 3, Md.

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669. Associate Professor—Associate Professorship at an eastern university in the field of aeronautical engineering, position involves both graduate and undergraduate instruction with a leading part being taken in the development of the graduate program. Doctor's degree preferred but will consider less if industrial experience offsets lack of the degree. Large off-campus graduate program now under way and in-residence program being developed.

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671. Aeronautical Engineer—M.S. and Ph.D. Two and a half years in fluid dynamics research. Three years' teaching in a major university. Desires position in teaching or research. Complete résumé on request. Please indicate nature and salary range of positions available.

670. Assistant or Chief Engineer, Development, or Research—M.S.M.E. Development, design, research in mechanical products and associated equipment, particularly rotating machinery and facilities. Includes ordnance, modern power plants, plant engineering. Organization and management skills. Twenty years' experience, seven at executive levels.

664. Representative—Executive—B.A. and M.B.A. degrees; 14 years' aircraft experience (sales service and production) Government buyer aircraft equipment. Field and factory representative. Automotive staff experience. Desires association with aviation division of commercial equipment firm. Midwest or Southwest preferred. Opportunity important. Brochure available.

663. Executive—Guided-missiles field; West Coast. Has worked for many years for large leading aircraft companies. Has broad experience in design (and preliminary design), manufacturing, and flight testing of all types of guided missiles. Ph.D. with excellent theoretical back-

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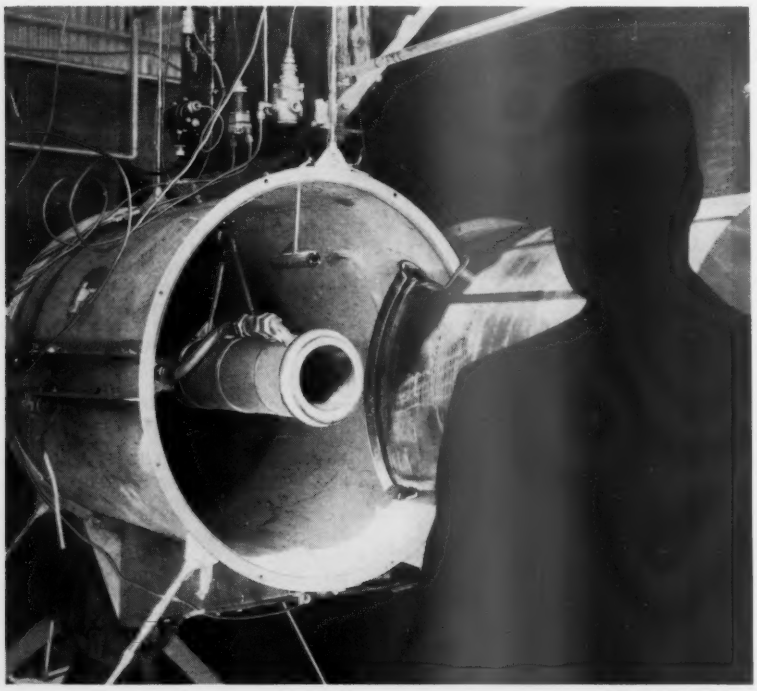

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Books

(*Continued from page 203*)

Naval Postgraduate School; Professor Stuart is at Lehigh University.

Contents: 1, Energy in Transition. 2, Stored Energy. 3, Energy Equations. 4, Reversible Processes and Cycles. 5, The Carnot Principle. 6, The Absolute Temperature Scale. 7, Entropy. 8, Properties and Property Relations; Solid, Liquid, and Vapor States. 9, Properties and Property Relations; Ideal Gases. 10, Property and Property Relations; Low-Pressure Gas and Gas-Vapor Mixtures. 11, Thermodynamic Properties; Non-Ideal Gases and Vapors. 12, Thermodynamics of Combustion. 13, Power-Generation Cycles; Condensing Fluids. 14, Power-Generation Cycles; Non-Condensing Fluids. 15, Heat-Pump and Refrigeration Cycles. 16, Flow of Compressible Fluids. 17, Dynamic Forces.

VIBRATION

Vibration Problems in Engineering. S. Timoshenko. 3rd Ed. New York, D. Van Nostrand Company, Inc., 1955. 468 pp., diagrs., figs. $8.75.

This new edition reflects the latest information on the subject. There are many new methods and greatly expanded material on nonlinear vibration, and new topics such as combined bending and torsional vibration of beams are included in an enlarged chapter on vibrations of elastic bodies. A considerable number of completely solved examples and numerous new problems have been added, and the use of Lagrangian equations has been dropped in favor of the more familiar d'Alembert's principle.

YEARBOOKS

Bulletin de L'Association Technique, Maritime et Aéronautique; No. 53, Session de 1954. Paris, Association Technique Maritime et Aéronautique, 1954. 736 pp. illus., diagrs., figs.

This volume contains 29 papers that were presented before the Association during the past year; some of aeronautical interest are listed below.

Conceptions et Possibilités du S.E. 5.000 Baroudeur, J. Dor. Systemes Vibratoires Comportant des Amortissements Visqueux Multiples. Applications aux Vibrations de Torsion des Lignes d'Arbres, A. Giraudeau. Le Porte-Avions en 1954, P. Barjot. Quelques Propriétés des Servo-Mécanisms Non-Linéaires Filtrés, G. Cahen. Note sur les Écoulements Plans Transsoniques; Généralisation du Nombre de Mach, R. Marchal et P. Servanty. Étude des Contraintes aux Congés de Raccordement de Têtes de Boulon Soumises à un Effort de Traction, J. Aubaud.